Response of Illinois Soils to Limestone

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By F. C. Bauer, Chief, Soil Experiment Fields

SOILS derived from limestone are usually productive and durable. This fact is widely recognized in such time-honored phrases as "a limestone country is a rich country." Not all soils, however, are derived from limestone and hence they may be naturally lime-deficient. Then, too, soils in humid climates tend to lose the lime materials naturally contained in them more or less rapidly thru the drainage waters and hence may become lime-deficient thru the operation of natural forces. With increasing deficiency of lime, soil productivity becomes lower and crop yields are reduced. The prevention and correction of lime deficiencies has become an important problem in soil management.

The effect on soil productivity of treatments to prevent and correct lime deficiencies has been studied for many years by the Illinois Agricultural Experiment Station. Field experiments have been conducted under widely varying soil conditions. The facts revealed have been widely disseminated thru publications and otherwise and profitably utilized by many farmers in Illinois and elsewhere, but because of the interest in and importance of such studies it seems desirable to bring all the facts together in summarized form. In this publication data have been assembled showing how various kinds of soil respond to applications of lime materials. Analysis of the relative effectiveness of different methods of applying limestone, including rates and frequency of liming, and of different finenesses of limestone and different forms, is reserved for future publications.

Forty Fields Furnish Data for Study

The first field experiments dealing with the influence of lime materials on Illinois soils were established in the fall of 1901. During the next seventeen years more than forty such fields were established over the state, and lime in some form, usually limestone, was given a prominent place in the treatment scheme.

In these experiments lime materials proved of different value on different soils. On many soils they were indispensable for successful crop production. On some soils they proved highly desirable for efficient production. On other soils they were without any physical effect, or the effect was so minor as to have no economic value. As the facts about these experiments became known among Illinois

farmers, widespread interest developed in the use of limestone for soil improvement, in which Illinois took the lead.

Many of the Illinois soil experiment fields are still in operation. With the passage of time they not only continue to demonstrate the

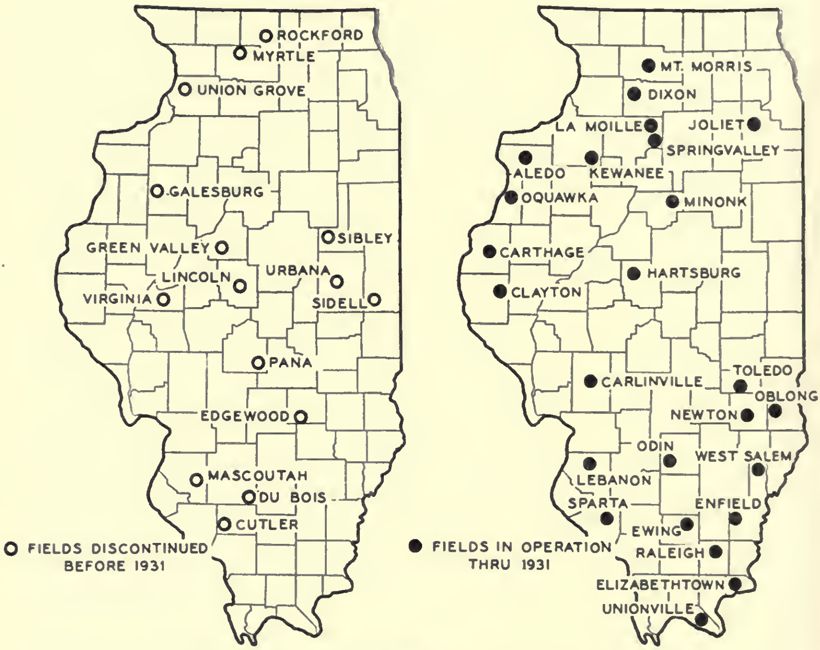

FIG. 1.—LOCATION OF SOIL EXPERIMENT FIELDS FURNISHING DATA FOR THIS PUBLICATION

Twenty-five of the soil experiment fields whose responses to limestone are analyzed in this publication had been in operation for periods varying from fourteen to thirty years up to and including the 1931 crop season. Fifteen other fields, operated for varying periods, were discontinued before 1931.

value of lime materials for soil-improvement purposes, but they also are bringing to light new management problems. The more recent results indicate, in addition to the facts stated above: *(1) that non-responsive soils may, with continued cultivation, become responsive; and (2) that the chemical, physical, and biological changes produced by the application of lime materials to the soil may in time create new conditions that must be taken into account in planning management practices.*

Forty of the fields established between 1901 and 1918 supply the

data for the present study. Twenty-five of these fields were still in operation in 1931, thus furnishing data for periods of fourteen to thirty years. Four of these fields were discontinued at the end of the 1931 season.

Widely Varying Soil Conditions Represented

A wide diversity of soil conditions and soil types is represented by the Illinois soil experiment fields, tho the types can be classified into ten general groups. The general characteristics of those soils, together with some information about their natural productiveness, certain of their chemical qualities, and the limestone applications made to them are outlined in Tables 1 and 3. The groups are arranged in descending order according to their natural productivity, a sequence which is maintained thruout this publication.

During the early years of these experiments no attempt was made to obtain detailed information about the character of the soils on which the fields were located. Only the general nature of the fields that were discontinued is therefore known.

Amounts and Kinds of Lime Materials Applied

No uniform plan for the application of lime materials was in effect during the early years of these experiments. Slaked lime was the chief material used in the earliest experiments. It was applied at rates ranging from 285 pounds to 10,000 pounds an acre. The usual application was 400 to 500 pounds an acre and was made at irregular intervals. Ground limestone in amounts ranging from 600 pounds to 20,000 pounds an acre was sometimes used. On some fields regular applications were made every year for several years. On other fields large amounts were applied, and usually no further applications were made for considerable time thereafter.

In 1909 and 1910 a more uniform practice was adopted. Crushed limestone became the standard material. Initial applications were made at the rate of 4 tons an acre, the plan being to follow with applications once during each rotation period at the annual acre-rate of 1,000 pounds, all to be made to the plowed soil just ahead of wheat seeding. This plan was followed on most fields until 1922 and 1923, when it became clear that on most plots more limestone was being applied than was necessary. All applications were then stopped, the plan being to apply no more limestone until the need for it should appear.

In these experiments the lime materials were usually applied in addition either to farm manure or to crop residues in order to repre-

TABLE 1.—SOIL GROUPS, NATURAL PRODUCTIVITY LEVELS, AND AMOUNTS OF LIMESTONE APPLIED TO ILLINOIS SOIL EXPERIMENT FIELDS IN OPERATION THRU 1931
(Soil groups and fields are listed in order of natural productivity)

Soil groups and fields	Stage of development	Natural productivity as average acre-yields		First crop year after limestone application	Total amount limestone applied
		All crops	Corn		
		lbs.	*bu.*		*tons*
I. *Dark soils with heavy, noncalcareous subsoils*					
Hartsburg, Logan county....	Young	2 600	49.0	1912	8.50
LaMoille, Bureau county....	Young	2 524	46.8	1913	7.75
Aledo, Mercer county.......	Young	2 396	54.8	1912	8.25
Minonk, Woodford county...	Young	2 388	48.2	1912	8.25
Average................	....	2 477	49.7	....	....
II. *Dark soils with noncalcareous subsoils*					
Kewanee, Henry county.....	Young	2 408	54.6	1915	6.75
III. *Brownish-yellow soils with open, noncalcareous subsoils*					
Springvalley, Bureau county..	Semimature	2 372	36.1	1915	6.75
IV. *Dark soils with open, noncalcareous subsoils*					
Mt. Morris, Ogle county.....	Semimature	2 210	44.0	1913	7.75
Dixon, Lee county..........	Semimature	2 068	40.1	1912	8.25
Average................	....	2 139	42.0	....	....
V. *Dark soils with impervious, calcareous subsoils*					
Joliet, Will county..........	Young (erosion)	1 690	30.1	1914	7.40
VI. *Dark soils with impervious, noncalcareous subsoils*					
Carthage, Hancock county...	Semimature	1 748	34.4	1913	7.75
Clayton, Adams county......	Semimature	1 723	35.2	1913	7.75
Lebanon, St. Clair county....	Semimature	1 661	26.5	1911	8.75
Carlinville, Macoupin county	Mature	1 476	29.0	1910	9.25
Average................	....	1 652	31.3	....	....
VII. *Sandy loams and sands*					
Oquawka, Henderson county..	Semimature	799	19.6	1914	7.90
VIII. *Yellow soils with noncalcareous subsoils*					
Unionville, Massac county...	Mature	684	14.2	1911	8.75
Enfield, White county.......	Mature	494	15.4	1913	7.75
Average................	....	589	14.8	....	....
IX. *Gray soils with impervious, noncalcareous subsoils*					
Oblong, Crawford county....	Old (moderately drained)	731	19.8	1912	8.25
Toledo, Cumberland county..	Old (poorly drained)	611	18.8	1913	7.25
Odin, Marion county........	Old (poorly drained)	608	18.0	1902	8.95
Raleigh, Saline county.......	Old (poorly drained)	558	14.1	1910	9.25
Sparta, Randolph county....	Old (very poorly drained)	527	12.7	1916	6.75
Newton, Jasper county......	Old (poorly drained)	500	10.1	1913	5.50
Ewing, Franklin county.....	Old (moderately drained)	482	10.7	1910	9.25
Average................	....	574	14.9	....	....
X. *Hilly land*					
Elizabethtown, Hardin county	Mature	325	11.5	1918	5.25

sent both the livestock and the grain systems of farming. In the grain system a legume, usually sweet clover, has been seeded in a small-grain crop and plowed down as a green manure for the following corn crop.

Crop Rotations Followed

Definite crop rotations have been practiced on all fields. Usually each crop in the rotation has been grown each year. These rotations have varied somewhat, but on many fields wheat, corn, oats, and clover have been the standard rotation. In the grain system of farming such a rotation is ideal for the use of sweet clover as a green manure for the corn crop. On a few fields a larger proportion of legumes was grown by adding alfalfa as a fifth crop in the rotation scheme.

DIFFERENCES AMONG SOILS IN RESPONSE TO LIMESTONE

The effectiveness of limestone in increasing crop yields on the different types of soil to be found in Illinois is indicated by the figures in Table 2 reporting the crop yields on twenty-four experiment fields in operation thru 1931. In order to have a common basis for comparisons, the crops grown and harvested, excluding the stover and the straw, have been converted into pounds.

Simple differences between the crop yields on limed and unlimed plots are one measure of the response of a soil to liming. Another useful measure is the *ratio* between such yields. Attention is called to such ratios in all the yield tables presented in this bulletin. Ratios of unity (1.000) or less indicate that the limestone applications failed to increase yields. Ratios greater than unity indicate that yields were increased and the extent of the increase in relation to yields from untreated plots. Thus a ratio of 1.365 represents a 36.5 percent increase in yield. Yields from limed plots, which are not always given, may be ascertained by multiplying the unlimed yield by its accompanying ratio.

Response as Related to Natural Productivity

It is evident from study of Table 2 that the response of soils to limestone tends to vary with their natural productivity—and that the lower the natural productivity of a soil, the greater its response to limestone. The dark soils with heavy, noncalcareous subsoils, ranking first in natural productivity, gave practically no response, the increase in crop yields on the four fields in this group averaging only 3 percent in the grain system. The hilly land, ranking lowest in natural productivity, gave the most pronounced response, the crop yields on the one field in this group being increased more than 150 percent by limestone applications. The response of the other eight groups of soils ranged between these two extremes.

TABLE 2.—RESPONSE OF ILLINOIS SOILS TO LIMESTONE, AS INDICATED BY CROP YIELDS FROM EXPERIMENT FIELDS OPERATED THRU 1931

(Figures indicate average annual acre-yields of all crops grown, excluding stover and straws)

Soil groups and fields in order of natural productivity	Manure system				Residues system			
	Manure (1)	Manure, limestone (2)	Increase (3)	Ratio $\frac{ML}{M}$ (4)	Residues (5)	Residues, limestone (6)	Increase (7)	Ratio $\frac{RL}{R}$ (8)
I. *Dark soils with heavy, noncalcareous subsoils*	*lbs.*	*lbs.*	*lbs.*		*lbs.*	*lbs.*	*lbs.*	
Hartsburg	3 102	3 418	316	1.097	2 931	2 879	− 52	.982
LaMoille	3 175	3 198	23	1.007	2 591	2 737	146	1.056
Aledo	3 095	3 401	306	1.099	2 486	2 705	219	1.088
Minonk	2 914	2 904	− 10	.997	2 377	2 371	− 6	.997
Average	3 071	3 230	159	1.052	2 596	2 673	77	1.030
II. *Dark soils with noncalcareous subsoils*								
Kewanee	3 020	3 158	138	1.046	2 326	2 588	262	1.112
III. *Brownish-yellow soils with open, noncalcareous subsoils*								
Springvalley	2 782	2 904	122	1.044	2 443	2 555	112	1.045
IV. *Dark soils with open, noncalcareous subsoils*								
Mt. Morris	2 956	3 273	317	1.107	2 042	2 579	537	1.263
Dixon	2 886	3 101	215	1.074	2 123	2 386	263	1.124
Average	2 921	3 187	266	1.091	2 082	2 482	400	1.192
V. *Dark soils with impervious, calcareous subsoils*								
Joliet	2 144	2 499	355	1.166	1 631	1 887	256	1.157
VI. *Dark soils with impervious, noncalcareous subsoils*								
Carthage	2 489	2 858	369	1.148	1 758	2 232	474	1.270
Clayton	2 491	2 953	462	1.185	1 805	2 361	556	1.308
Lebanon	2 386	2 666	280	1.113	1 476	1 890	414	1.280
Carlinville	1 922	2 616	694	1.361	1 472	2 010	538	1.365
Average	2 322	2 773	451	1.194	1 628	2 123	495	1.304
VII. *Sandy loams and sands*								
Oquawka	1 386	2 334	948	1.684	947	1 741	794	1.838
VIII. *Yellow soils with noncalcareous subsoils*								
Unionville	973	1 437	464	1.477	600	1 040	440	1.733
Enfield	736	1 660	924	2.255	537	1 174	637	2.186
Average	854	1 548	694	1.813	569	1 107	538	1.946
IX. *Gray soils with impervious, noncalcareous subsoils*								
Oblong	1 090	1 870	780	1.716	856	1 363	507	1.592
Toledo	890	1 682	792	1.890	598	1 215	617	2.032
Odin	.....	.....	...	.....	660	924	264	1.400
Raleigh	891	1 775	884	1.992	563	1 246	683	2.214
Sparta	862	1 583	721	1.836	446	929	483	2.083
Newton	836	1 515	679	1.812	454	923	469	2.033
Ewing	781	1 805	1 024	2.311	427	1 095	668	2.564
Average	892	1 705	813	1.911	572	1 099	527	1.921
X. *Hilly land*								
Elizabethtown	618	1 384	766	2.239	391	1 000	609	2.558

The relation between the natural productivity of a soil and its response to limestone is not, however, entirely consistent, as may be seen from Fig. 2. Groups III and V, for example, show a somewhat

low response in relation to their natural productive levels, while Group VII shows an unusually high response. Each of these three groups of soils, however, is represented by only a single field, a fact that may partially explain the irregularities, especially since these fields represent in some respects the extremes of their groups. The Joliet field, representing Group V, is exceptionally deficient in phosphorus; the

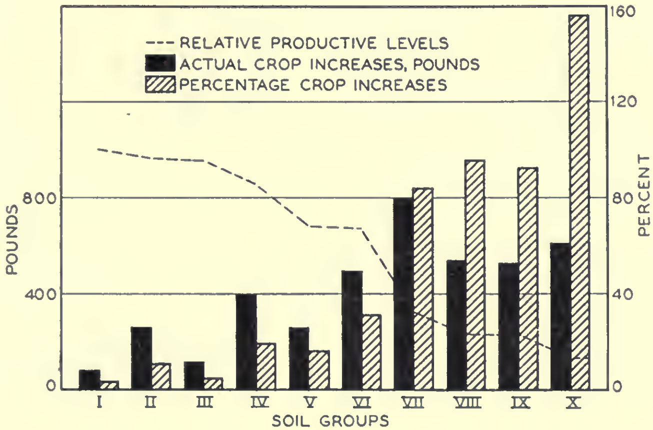

FIG. 2.—COMPARATIVE RESPONSE OF TEN GROUPS OF ILLINOIS SOILS TO LIMESTONE APPLICATIONS

The black bars represent pounds of crop increase produced by limestone, the shaded bars the percentage increases resulting from limestone. The natural productivity of the various soil groups compared with Group I is shown by the broken line. It is evident that the response of a soil to limestone varies more or less inversely with its natural productivity. Highly productive soils tend to respond the least and the less productive soils the most.

Oquawka field, representing Group VII, is exceptionally sandy; and the Springvalley field, representing Group III, has a highly permeable soil profile which permits deeper feeding of the crop plants.

Quite different relationships between the actual yield increase on a given soil and the percentage yield increase (response ratio) are evident among the various soil groups. For all of the dark-colored groups the actual yield increases are more striking than the response ratios, while for the sandy and the light-colored groups the response ratios are more striking than the actual yield increases. Leaving the sandy group out of consideration and comparing the light-colored groups (VIII, IX, and X) with the least productive dark-colored group (VI), one observes that there is not a great deal of difference in the actual yield increases resulting from the use of limestone on

these soils. Evidently when natural productivity levels are very low, differences in level make little difference in the actual increases that can be obtained by applications of limestone. With actual increases in yield remaining the same, percentage responses will of course rise as the natural levels of productivity decline. Deficiencies other than limestone, along with other characteristics peculiar to these light-colored soils, such as stage of development, are undoubtedly important factors in the variations which they have shown in their response to limestone.

Response as Related to Chemical Factors

A study of limestone responses as related to the natural productivity of the soil has increasing significance when one examines some of the chemical properties of the soil. Such chemical data are presented in Table 3. These data include those obtained by the Comber potassium-thiocyanate test, widely used as a rapid field test; those obtained from hydrogen-ion determinations, in terms of pH,[1] a measure of active acidity or alkalinity; those obtained by the Bray-DeTurk lime-requirement test,[2] a field test based on the deficiency of exchangeable calcium; and some laboratory data pertaining to replaceable bases.[3]

Replaceable-base data are now generally regarded as satisfactorily explaining the lime responses of soils. At this point it is of interest to consider in greater detail the data presented in Table 3. In Columns 2, 3, and 4 are shown the acre-amounts of replaceable calcium and magnesium in the different soil groups. In no group are the totals of these elements (Column 4) and the total base-exchange capacity of the soil (Column 5) equal on the unlimed land. The calcium and magnesium are insufficient to satisfy the total base-exchange capacity of the soil. This means that other replaceable bases are present, or

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[1]A pH value of 7.0 represents neutrality. Decreasing values represent increasing acidity, and increasing values represent increasing alkalinity. Soils of good productivity are usually slightly acid, ranging in pH values from 6.0 to 7.0. A soil with a pH value as low as 4.0 is exceedingly unfavorable to the growth of ordinary crops.

[2]Method described in *Soil Science* **32**, 5:329 (1931).

[3]When soils are mixed with salt solutions, a rapid exchange of bases takes place between the soil and the salt. The character and the quantity of the bases entering into this exchange depend upon the nature of the soil and the salt solution used. The calcium, magnesium, and other bases shown by such tests to be present in replaceable form are commonly referred to as "exchangeable bases." Chemists have found the results of such tests useful in explaining many behaviors of soils. Such tests are now widely used in soil-acidity and lime-response studies.

Soil groups and fields in order of natural productivity	Total application of limestone per acre	Replaceable-base data on acre basis						Reaction		Lime requirement per acre[4]
		Calcium	Magnesium	Total calcium and magnesium	Base exchange capacity[2]	Degree of saturation	Bases needed for 80 percent saturation	Hydrogen-ion concentration[3]	Comber acidity KSCN	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
I. *Dark soils with heavy, noncalcareous subsoils*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*perct.*	*lbs.*	pH		*tons*
Hartsburg	0	23 400	6 300	29 700	37 600	79	400	6.6	None	0
Hartsburg	8.50	26 700	12 200	38 900	37 800	100	0	7.4	None	0
II. *Dark soils with noncalcareous subsoils*										
Kewanee	0	......	......	16 400	29 300	55	7 000	5.3	High	6
III. *Brownish-yellow soils with open, noncalcareous subsoils*										
Springvalley	0	......	......	14 100	18 600	75	800	5.8[5]	Low	1
IV. *Dark soils with open, noncalcareous subsoils*										
Mt. Morris	0	10 100	5 000	15 100	26 200	58	5 900	5.3	Medium	3
Mt. Morris	7.75	12 800	7 000	19 800	25 000	79	200	7.2	None	0
V. *Dark soils with impervious, calcareous subsoils*										
Joliet	0	13 600	4 400	18 000	27 400	66	3 900	5.4	Medium	3
Joliet	7.40	16 900	5 200	22 100	26 500	83	0	6.8	Slight	0
VI. *Dark soils with impervious, noncalcareous subsoils*										
Clayton	0	10 700	3 900	14 600	19 900	73	1 300	5.5[5]	Medium	2
Clayton	7.75	15 700	4 000	19 700	20 900	94	0	...	None	0
VII. *Sandy loams and sands*										
Oquawka	0	900	300	1 200	3 400	35	1 500	5.7	Low	1
Oquawka	7.90	2 700	400	3 100	3 800	82	0	7.7	None	0
VIII. *Yellow soils with noncalcareous subsoils*										
Unionville	0	1 900	900	2 800	10 000	28	5 200	5.2	Medium	4
Unionville	8.75	6 800	500	7 300	8 800	83	0	7.5	None	0
IX. *Gray soils with impervious, noncalcareous subsoils*										
Ewing	0	1 100	700	1 800	10 800	17	6 800	4.9	Very high	5
Ewing	9.25	8 100	700	8 800	11 400	77	300	7.3	None	0
X. *Hilly land*										
Elizabethtown	0	1 900	1 200	3 100	8 800	35	3 900	5.3[5]	Low	3
Elizabethtown	5.25	8 200	1 200	9 400	10 200	92	0	...	None	0

[1]Analyses made by R. H. Bray, Associate in Soil Survey Analysis. [2]Neutral salt method. [3]Hydrogen electrode. [4]Bray and DeTurk method (*Soil Science*, 32, 5:329). [5]Quinhydrone electrode.

else that hydrogen (indicating acidity) has taken their places. The pH values of the soil (Column 8) indicate that hydrogen is present.

The amount of replaceable bases in the soil in proportion to the base-exchange capacity of the soil is indicated in Column 6 under the heading "degree of saturation." For unlimed land there is considerable variation in the degree of saturation among the several soil groups. The Hartsburg field, representing the dark soils with heavy, noncalcareous subsoils, contains enough replaceable calcium and magnesium to satisfy 79 percent of the total capacity of the soil to absorb such bases. The Ewing field, however, representing the gray soils with impervious, noncalcareous subsoils, shows a saturation of only 17 percent. The other soils range between these extremes.

It is now generally believed that when the soil contains sufficient calcium and magnesium in replaceable form to satisfy about 80 percent of the base-exchange capacity of the soil, limestone is not likely to be needed for crop production. When this value falls below 80 percent, indicating thereby decreasing availability of calcium and magnesium, limestone is needed for crop production. To say that a soil gives an acid reaction, or that it is an "acid soil," is another way of saying that it is deficient in available bases, especially in calcium and magnesium. So far as the growth of crops is concerned, calcium is the more important of these two bases.

With these facts in mind it will be of interest to compare the degree of saturation of the different soils groups with their natural productivity levels and limestone responses. Such comparisons reveal striking differences between the dark-colored soils and the sandy and light-colored soils (Fig. 3). In the dark-colored groups of soils, which exhibit relatively high productive levels and rather low responses to limestone, the degree of saturation averages about 70 percent. In the light-colored groups, which are low in productivity and high in limestone response, the degree of saturation averages about 25 percent.

Some of the individual soil groups within these two major classes of soils (dark colored and light colored) do not, however, conform perfectly to the above relationship. Group II, represented by the Kewanee field, for instance, falls to 55 percent saturation, yet natural productivity is high and limestone response is low. Referring to Column 5 of Table 3, one observes that the base-exchange capacity of this soil is high even tho the total replaceable calcium and magnesium is somewhat low in comparison. This soil also shows a fair degree of acidity. Apparently the use of the 80-percent saturation level as an indicator for the need of limestone on a soil of this kind

is too high. Soils with a high base-exchange capacity may be able to liberate more available calcium for crop growth than soils of low exchange capacities, even tho the total amount of replaceable calcium and magnesium is relatively low. On the Clayton field, representing Group VI, with 73 percent saturation, the productivity level is lower and the response to limestone higher than on the Kewanee field. The total base-exchange capacity of the soil of the Clayton field is, however, very much lower than that of the Kewanee field. For the Clayton field, therefore, the 80-percent saturation level may be a good index to the need for limestone. The same conditions prevail to some extent in the light-colored soils.

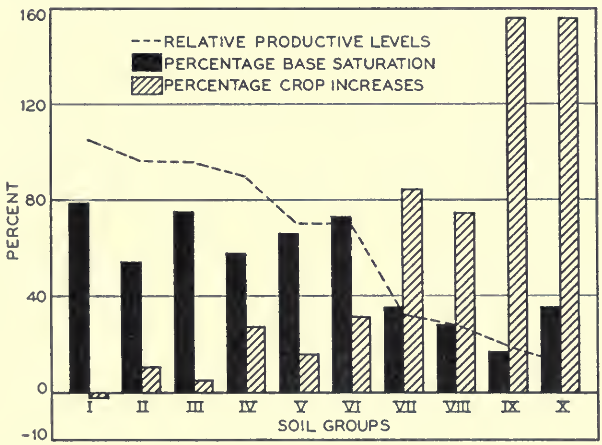

Fig. 3.—Degree of Base Saturation and Limestone Response in Ten Groups of Illinois Soils

The base-exchange capacity of the highly productive soils tends to be more completely satisfied than does the base-exchange capacity of the soils of lower productivity, as shown by the percentage base saturation. Since the response that a soil will make to limestone applications is more or less closely related to its percentage base saturation, the value of proper chemical tests in detecting soils or fields that are deficient in limestone is evident.

When the results of the various tests for lime requirement or acidity (Table 3) are compared with each other it is evident that there is not exact agreement among them. The Kewanee and Mt. Morris fields, for instance, possess about the same percentage saturation and pH values, but the amounts of acidity, as indicated by the Comber test, and the lime requirements, as indicated by the Bray-DeTurk tests, differ. This is to be expected since the tests are based on different principles and also because there are marked differences

in the chemical nature of the various kinds of soil. Because of the complexity of these various relationships, the problem of clarifying the underlying principles of soil acidity will probably always be beset with some difficulties. So far as the farmer is concerned, however, some of the simpler tests, such as the Comber field test for acidity, described in Illinois Circular 346, or the Bray-DeTurk lime-requirement test,[1] will be of great service in quickly determining the approximate lime needs of the soil or in detecting those fields or areas that will grow various legume crops without the application of lime materials.

Data From Fields Discontinued Before 1931

The effects of lime treatments in the crop-residues system of farming on the soil experiment fields discontinued before 1931 are shown in Table 4.

During the early years of the experiment fields no attempt was made to obtain detailed information about the character of the soil on which the fields were located. Only the general nature of the soil of most of the fields discontinued before 1931 is known. Neither was any

TABLE 4.—ILLINOIS SOIL EXPERIMENT FIELDS DISCONTINUED BEFORE 1931, SHOWING RESPONSE TO LIMESTONE IN RESIDUES SYSTEM OF FARMING

Fields	Duration of experiment	Natural productivity, average corn yield	Lime applied		Average annual acre-yields of all crops			
			Kind	Total amount	Residues	Residues, lime	Increase	Ratio $\frac{RL}{R}$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dark-colored soils		*bu.*		*tons*	*lbs.*	*lbs.*	*lbs.*	
Virginia	1902–23	57.8	Slaked Limestone	.14 7.00	2 201	2 038	−163	.926
Rockford	1906–19	49.5	Limestone	6.90	2 598	2 511	− 87	.967
Lincoln	1905–10	45.7	Slaked	.58	2 437	2 501	64	1.022
Galesburg	1904–18	58.3	Limestone	4.65	2 535	2 596	61	1.024
Myrtle	1906–09	43.7	Limestone	.70	2 189	2 331	142	1.065
Sibley	1902–13	47.5	Hydrated	.20	2 006	2 193	187	1.093
Sidell	1913–27	43.6	Limestone	8.00	2 165	2 403	238	1.110
Mascoutah	1902–13	34.2	Slaked Limestone	.58 3.06	1 038	1 156	118	1.114
Urbana	1902–29	54.6	Slaked Limestone	.42 7.00	2 332	2 633	301	1.129
Uniongrove	1912–23	29.8	Limestone	7.50	2 119	2 546	427	1.202
Pana	1913–22	26.5	Limestone	8.00	1 362	1 834	472	1.346
Average	....	44.7	....	....	2 603	2 733	130	1.050
Light-colored soils								
Edgewood	1903–11	30.9	Limestone	10.00	2 472	2 801	329	1.130
DuBois	1902–23	11.2	Slaked	5.00	591	840	249	1 431
Cutler	1902–17	18.2	Slaked Limestone	3.20 4.00	704	1 067	363	1.515
Average	....	17.9	....	....	1 256	1 569	313	1.249
Sand soils								
Greenvalley	1902–07	47.0	Slaked	.16	1 877	1 601	−276	.853

[1]*Soil Science* **32.** 5:329 (1931).

uniform practice followed in the early use of lime materials. Nevertheless the results from these fields are of interest, especially since they correspond fairly closely to the results obtained from the twenty-five fields still in operation in 1931.

More or less variation in the natural productivity of the fields included in the group of dark-colored soils is indicated by the corn yields recorded in Column 2 of Table 4. This variation is due mainly to the fact that several different soil types are represented in this group. The interesting fact about the data from these fields, however, is that the response to lime varies more or less inversely with the natural productivity of the soil. This is evident from a study of the figures in the last two columns. Those fields producing the highest average yields of corn without treatment have given little or no response to lime. As the natural productivity level declines, the response to lime tends to increase. On the Pana field, for example, which has the lowest average yield of corn, all crop yields have been increased more than a third by the use of limestone.

Besides differences in response to limestone that result from differences in the natural productivity of the soil, we find differences in response because of the type of crop rotation employed. On a lime-deficient soil, rotations that include the liberal use of legume crops appear to make better use of applied limestone than do rotations that consist almost entirely of grain crops. The Urbana field, for example, on which alfalfa was grown regularly as one of the rotation crops, showed a very favorable response to limestone. On fields where the rotations consisted chiefly of grain crops, the response to limestone was somewhat unfavorable. The response of legumes to limestone is especially fortunate, for legumes improve the soil and may generally be regarded as high-profit crops.

The light-colored soils are not extensively represented by these fields. What evidence there is agrees with that of the fields reported in Table 2 in showing the productive levels of such soils to be much lower than those of the dark-colored soils and the degree of response to lime treatments to be considerably higher.

On the one sandy field represented, the crops showed no response to the lime applied.

RESPONSE OF INDIVIDUAL CROPS TO LIMESTONE

Corn

The behavior of individual crops on various kinds of limed soils is also a matter of much interest. Increases in the yields of corn resulting from the application of limestone are shown graphically in Fig. 4 and are also illustrated in Figs. 5 and 6.

The natural productivity of the soil is clearly an important factor in the response of corn to applied limestone. The light-colored, less

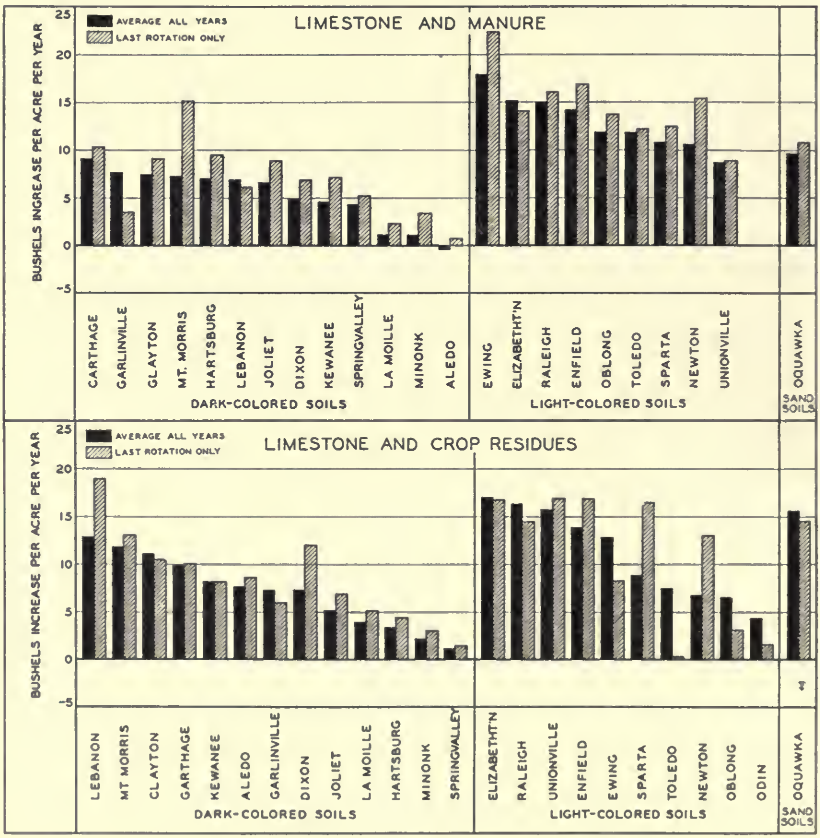

FIG. 4.—INFLUENCE OF LIMESTONE ON CORN YIELDS

The dark-colored soils tend to give the largest increases in yields for limestone in the crop-residues system, while on the light-colored soils limestone gives the largest increases when used with manure.

productive soils have given significantly larger increases than the dark-colored, more productive soils. More or less variation in response on the different fields within the major soil groups is also evident. In the dark-colored group, for example, the naturally more productive soils tend to give the least response. In the light-colored

FIG. 5.—ON SOILS OF NATURALLY LOW PRODUCTIVITY LIMESTONE IS USUALLY STRIKINGLY EFFECTIVE

The acre-yield of corn on the unlimed land was 1 bushel, while more than 50 bushels were harvested from the limed land. Limestone is indispensable on many soils. *Ewing field, 1928.*

group, the relationship between the natural productivity of a soil and the response made by corn to limestone applications is not so pronounced.

On the dark-colored soils the residues system has caused larger increases in corn yields than the manure system. On the light-colored soils the manure system has given the larger crop increases. Apparently the manure takes care of the major soil deficiencies in the dark-colored soil, and hence there is less need for limestone.

With the light-colored soils, however, deficiencies other than lime-

TABLE 5.—MANURE SYSTEM: RESPONSE OF WHEAT, CORN, OATS, AND HAY TO LIMESTONE ON ILLINOIS SOIL EXPERIMENT FIELDS
(Yields are given as annual acre averages)

Soil groups and fields in order of natural productivity	Wheat yields[1]		Corn yields[1]		Oat yields[1]		Hay yields[1]	
	Manure only (1)	Ratio $\frac{ML}{M}$ (2)	Manure only (3)	Ratio $\frac{ML}{M}$ (4)	Manure only (5)	Ratio $\frac{ML}{M}$ (6)	Manure only (7)	Ratio $\frac{ML}{M}$ (8)
I. *Dark soils with heavy, noncalcareous subsoils*	*bu.*		*bu.*		*bu.*		*tons*	
Hartsburg	28.4	1.194	56.6	1.125	52.7	1.104	2.21	1.063
LaMoille	38.9	1.018	58.5	1.018	74.3	.981	2.94	.993
Aledo	34.5	1.052	68.9	.996	67.6	1.044	2.37	1.101
Minonk	33.4	.952	58.8	1.019	62.4	.970	2.47	1.008
Average	33.8	1.047	60.7	1.036	64.2	1.020	2.50	1.036
II. *Dark soils with noncalcareous subsoils*								
Kewanee	32.5	1.083	66.5	1.069	71.5	1.021	2.24	1.053
III. *Brownish-yellow soils with open, noncalcareous subsoils*								
Springvalley	39.6	1.002	46.4	1.093	48.0	1.077	2.67	1.026
IV. *Dark soils with open, noncalcareous subsoils*								
Mt. Morris	27.3	1.198	58.8	1.122	67.9	1.053	2.31	1.195
Dixon	28.9	1.104	57.3	1.086	64.0	1.053	2.30	1.070
Average	28.1	1.149	58.0	1.105	66.0	1.053	2.30	1.135
V. *Dark soils with impervious, calcareous subsoils*								
Joliet	24.6	1.163	39.0	1.169	63.2	1.027	1.44	1.146
VI. *Dark soils with impervious, noncalcareous subsoils*								
Carthage	24.2	1.161	44.7	1.203	43.2	1.130	2.32	1.121
Clayton	23.1	1.169	53.6	1.138	47.2	1.106	2.13	1.263
Lebanon	24.9	1.177	38.2	1.183	36.9	1.119	2.22	1.158
Carlinville	23.2	1.293	37.9	1.203	42.3	1.158	1.83	1.481
Average	23.9	1.197	43.6	1.179	42.4	1.127	2.12	1.245
VII. *Sandy loams and sands*								
Oquawka	12.7	1.504	25.4	1.378	....	.....	.11	13.818
VIII. *Yellow soils with noncalcareous subsoils*								
Unionville	8.4	1.786	20.5	1.424	....	.....	.86	1.488
Enfield	8.7	2.287	22.9	1.620	17.6	1.682	.29	5.034
Average	8.5	2.047	21.7	1.525	17.6	1.682	.58	2.362
IX. *Gray soils with impervious, noncalcareous subsoils*								
Oblong	12.3	1.683	29.4	1.401	25.0	1.336	.68	2.368
Toledo	13.2	1.894	28.2	1.415	19.5	1.615	.41	3.366
Raleigh	7.3	2.699	26.9	1.558	17.2	1.640	.48	2.833
Sparta	9.2	2.065	18.1	1.591	....	.....	.00	(1.85[2])
Newton	2.0	6.600	16.4	1.634	24.4	1.443	.79	1.519
Ewing	5.9	3.830	22.3	1.803	14.9	2.094	.26	5.038
Average	8.3	2.410	23.5	1.549	20.2	1.579	.44	3.295
X. *Hilly land*								
Elizabethtown	6.9	2.029	18.9	1.799	....	.....	.27	5.111

[1]Yields on the limed land can be determined by multiplying the yields on the unlimed land by their response ratios. [2]Actual yield for limestone.

stone are important, and before the full effects of limestone can be realized these deficiencies must be corrected. That the application of manure does tend to correct important soil deficiencies on these soils

TABLE 6.—RESIDUES SYSTEM: RESPONSE OF WHEAT, CORN, OATS, AND HAY TO LIMESTONE ON ILLINOIS SOIL EXPERIMENT FIELDS

(Yields are given as annual acre averages)

Soil groups and fields in order of natural productivity	Wheat yields[1]		Corn yields[1]		Oat yields[1]		Hay yields[1]	
	Residues only (1)	Ratio $\frac{RL}{R}$ (2)	Residues only (3)	Ratio $\frac{RL}{R}$ (4)	Residues only (5)	Ratio $\frac{RL}{R}$ (6)	Residues only (7)	Ratio $\frac{RL}{R}$ (8)
I. *Dark soils with heavy, noncalcareous subsoils*	*bu.*		*bu.*		*bu.*		*tons*	
Hartsburg	30.8	.922	69.2	1.052	50.2	.972	2.00	.995
LaMoille	37.5	1.056	53.3	1.073	69.8	1.063	2.00	1.045
Aledo	31.2	1.099	62.8	1.123	70.8	1.047	1.82	1.000
Minonk	33.1	.909	57.7	1.036	61.4	1.020	1.75	.966
Average	33.2	.997	59.2	1.071	63.0	1.030	1.89	1.000
II. *Dark soils with noncalcareous subsoils*								
Kewanee	31.8	1.075	59.0	1.139	61.1	1.083	1.38	1.174
III. *Brownish-yellow soils with open, noncalcareous subsoils*								
Springvalley	39.3	1.023	47.8	1.040	48.7	1.121	2.33	1.030
IV. *Dark soils with open, noncalcareous subsoils*								
Mt. Morris	24.7	1.279	50.8	1.232	58.3	1.294	1.57	1.293
Dixon	26.1	1.123	49.3	1.156	57.9	1.173	1.54	1.130
Average	25.4	1.197	50.0	1.196	55.9	1.231	1.56	1.211
V. *Dark soils with impervious, calcareous subsoils*								
Joliet	22.2	1.081	33.8	1.151	55.9	1.061	.99	1.162
VI. *Dark soils with impervious, noncalcareous subsoils*								
Carthage	21.0	1.371	49.2	1.201	52.2	1.130	1.53	1.248
Clayton	22.1	1.204	47.6	1.220	52.9	1.191	1.62	1.377
Lebanon	21.9	1.311	34.2	1.374	41.4	1.488	1.26	1.294
Carlinville	18.4	1.402	33.2	1.223	39.8	1.314	1.96	1.316
Average	20.8	1.317	41.0	1.254	46.5	1.267	1.59	1.314
VII. *Sandy loams and sands*								
Oquawka	12.1	1.471	20.8	1.745	....	.....	.11	13.364
VIII. *Yellow soils with noncalcareous subsoils.*								
Unionville	7.4	2.054	16.2	1.969	....	.....	.59	1.458
Enfield	7.7	2.338	19.0	1.731	16.9	2.308	.18	6.722
Average	7.6	2.184	17.6	1.841	16.9	2.308	.38	2.710
IX. *Gray soils with impervious, noncalcareous subsoils*								
Oblong	11.3	1.726	24.5	1.269	32.3	1.542	.63	2.286
Toledo	11.3	2.000	18.5	1.405	17.3	2.058	.37	3.594
Odin	10.0	1.870	20.6	1.209	....	.....	.40	2.650
Raleigh	7.7	2.143	18.3	1.891	16.8	1.869	.28	2.929
Sparta	5.4	3.315	15.2	1.586	....	.....	.00	(1.39[2])
Newton	1.7	5.582	10.3	1.650	17.0	2.006	.55	1.727
Ewing	3.4	5.912	12.3	2.049	15.8	2.297	.21	4.905
Average	7.2	2.472	17.1	1.526	19.8	1.889	.35	3.296
X. *Hilly land*								
Elizabethtown	4.2	2.405	14.7	2.170	....	.....	.16	2.938

[1]Yields on the limed land can be determined by multiplying the yields on the unlimed land by their response ratios. [2]Actual yield for limestone.

and hence to make possible a greater response to limestone is confirmed by a comparison of the long-time crop yields and the yields of the last rotation. In the manure system every field in the light-colored

group, with the exception of the Elizabethtown field, has given a greater response to limestone during the last rotation than during the complete period of experimentation, a fact that indicates the increasing value of limestone applications. In the residues system only four fields in the light-colored group show such increases and some have

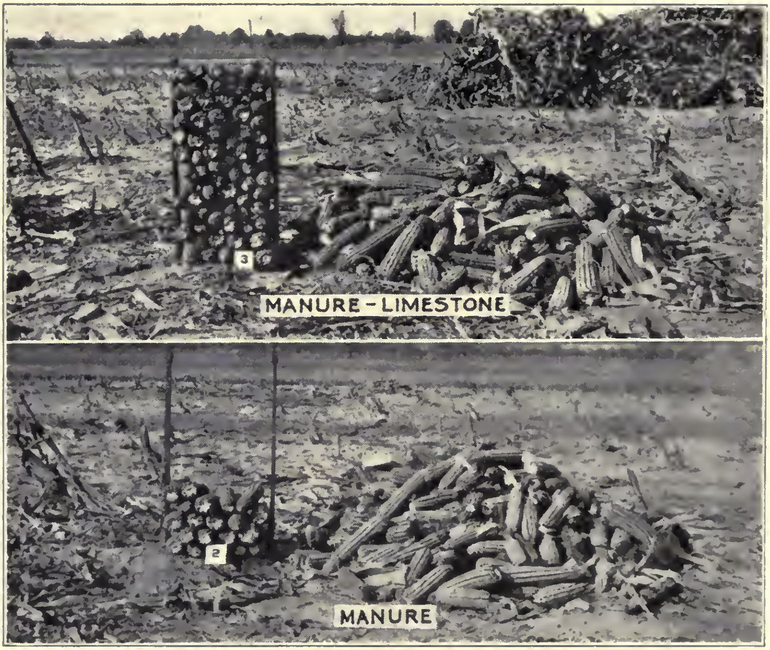

FIG. 6.—LIMESTONE IMPROVES BOTH YIELD AND QUALITY OF CORN

The acre-yield of corn where the land was treated with manure and limestone was 49.1 bushels, and 11.3 bushels were reasonably sound ears. The total yield on the land receiving only manure was 35.1 bushels, and only 3.3 bushels were reasonably sound. *Toledo field, 1933.*

shown rather large decreases. Experiments indicate that the fields in the light-colored group are deficient in potash, a deficiency which manure corrects.

Wheat

The influence of limestone on wheat yields (Fig. 7) is, in general, similar to its influence on corn yields (Fig. 4), the light-colored, less productive soils giving larger increases than the dark-colored, more productive soils. Within the major soil groups, moreover, there is a variation in response among the different fields, the naturally less productive fields showing the greatest increases in yields. Wheat in-

creases from limestone application have been smaller, however, than corn increases. On the more productive dark-colored soils the wheat increases have been negligible.

Wheat grown on light-colored soils has been especially responsive to limestone in the residues system, a noticeable contrast to the re-

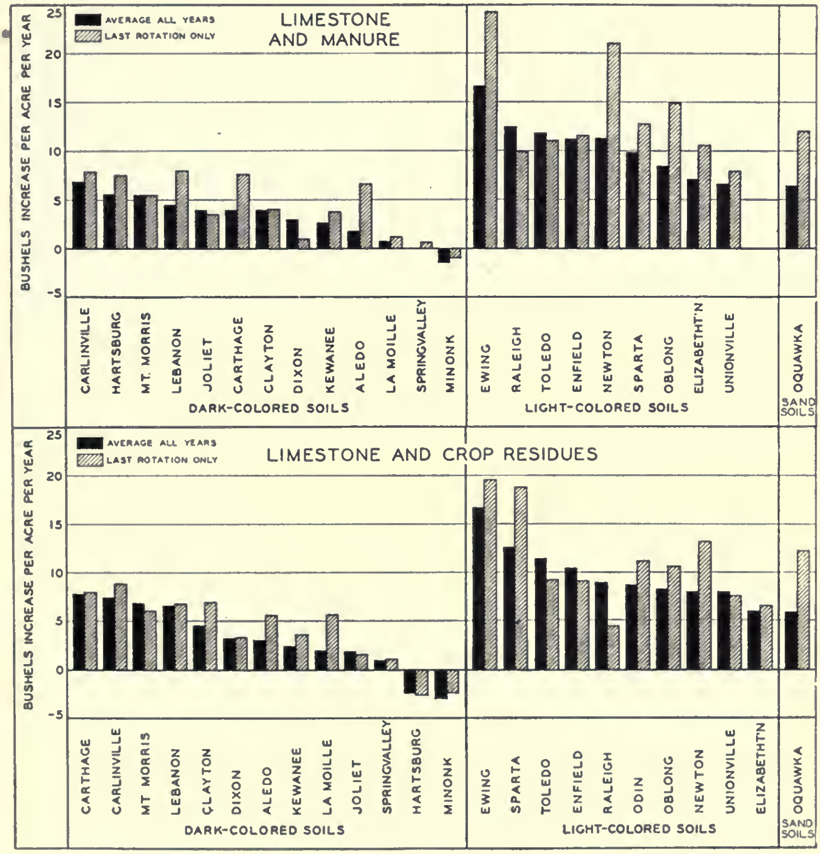

FIG. 7.—INFLUENCE OF LIMESTONE ON WHEAT YIELDS

Wheat is not strikingly responsive to limestone on dark-colored soils as a group, but on light-colored soils it tends to be much more responsive than corn.

sponse of corn under similar conditions. During the last rotation period all the fields on light-colored soils except four gave an average annual increase that was larger than the increase for the longer period. Apparently other soil deficiencies, such as a low supply of potash, do not check wheat yields so much as they do corn yields. On the

Raleigh field, however, soil deficiencies other than limestone have retarded the yields during the last rotation period.

FIG. 8.—ON LAND OF LOW PRODUCTIVITY WHEAT YIELDS ARE LIKELY TO BE VERY POOR WITHOUT LIMESTONE

With manure alone, only 1 bushel of wheat was produced on the above field. Twenty-four bushels were harvested on land that had received both limestone and manure. *Newton field, 1930.*

FIG. 9.—WHEAT YIELDS ON SAND LAND WERE MORE THAN DOUBLED BY LIMESTONE

The unlimed field yielded at the rate of 15 bushels of wheat an acre. The limed field produced 35 bushels an acre. *Oquawka field, 1930.*

Oats

The influence of limestone on oat yields has been most marked on the light-colored soils, especially in the residues system (Fig. 10). In the manure system, however, limestone has tended to be less effective

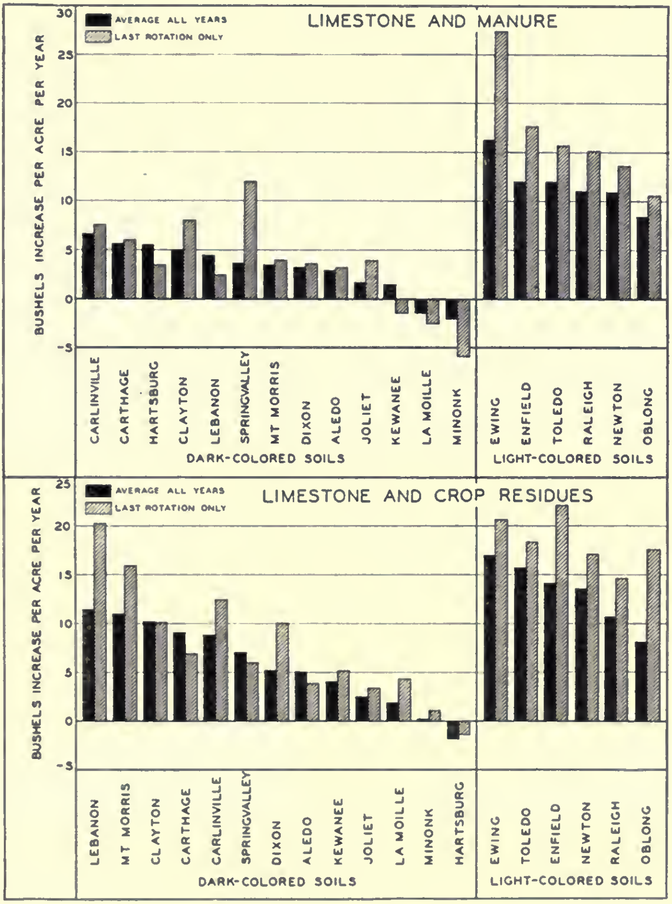

FIG. 10.—INFLUENCE OF LIMESTONE ON OAT YIELDS

Limestone has produced greater increases in yields of oats on the light-colored soils than on the dark-colored soils. On both groups of soils the residues system has given better results than the manure system.

on all fields. On the dark-colored soils as a group it was relatively ineffective. In general the oat rotation yields, compared with long-time yields, reveal increasing responses, especially in the light-colored group. There is no particular evidence that the response of the oat

crop has been interfered with, especially, by deficiencies of other nutrients.

On the whole, oats appear to be less responsive to limestone than either corn or wheat.

Hay Crops

Study of the influences of limestone on the growth and yield of hay is somewhat complicated by the fact that the same hay crops were not used on all fields. On many of the dark-colored soils red clover

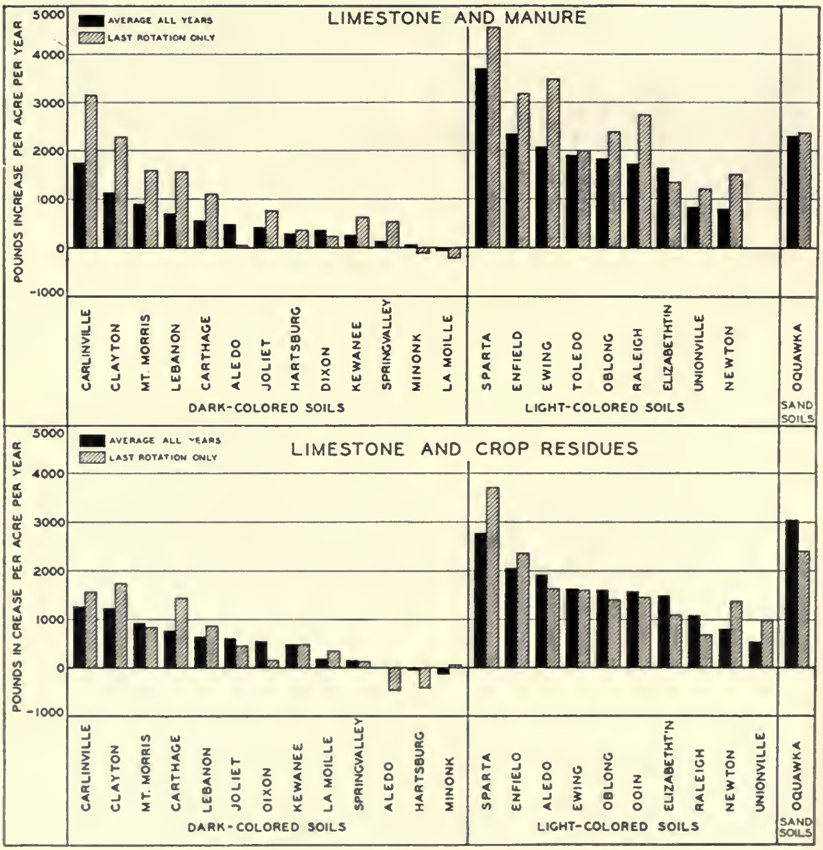

FIG. 11.—INFLUENCE OF LIMESTONE ON HAY CROPS

Limestone applications have increased hay yields in about the same way as they have the grain yields. In the manure system, increases during the last rotation have tended to be larger than during the longer period. In the residues system this tendency has not been so apparent, the absence of other nutrients making it impossible for limestone to become fully effective.

was the usual hay crop grown, on some fields alfalfa was grown, and on others a mixture of red clover and alfalfa was used. In recent years a mixture of alsike clover, red clover, alfalfa, and timothy has been used on the light-colored soils. In the earlier years alsike and red clover were used alone. When the hay crops have failed, soybeans have usually been substituted.

FIG. 12.—LIMESTONE MAKES GOOD HAY YIELDS POSSIBLE ON SOILS OF LOW NATURAL PRODUCTIVITY

A mixed hay seeding produced no crop where only manure was applied. It yielded over 2 tons of good hay an acre on the land that received limestone and manure. The mixed hay contained considerable alfalfa. *Enfield field, 1931.*

The largest responses of harvested hay crops to limestone have been obtained on the light-colored soils (Figs. 11 and 12). Rather low responses have been obtained on a number of the dark-colored soils. Limestone has thus affected the hay crops in a way somewhat similar to the way in which it has affected the grain crops.

In general the average annual increases in weight of crop materials during the last rotation, in both the residues and the manure systems, are as great as those obtained for the longer period, or greater. In the manure system, especially, the response has been favorable during the last rotation; but in the residues system the response for the last rotation has been similar to that for the longer period. The slowing up of the response in the residues system probably indicates a deficiency of nutrients not supplied by limestone or crop residues.

On the whole the response of the hay crops to limestone has been

sufficiently favorable to indicate the need of limestone for hay production on many Illinois soils.

Comparative Responses of Above Crops

The relative importance of limestone for wheat, corn, oats, and hay is indicated by the data recorded in Tables 5 and 6 and Fig. 13. The crop yields are given for the unlimed land, and the influence of

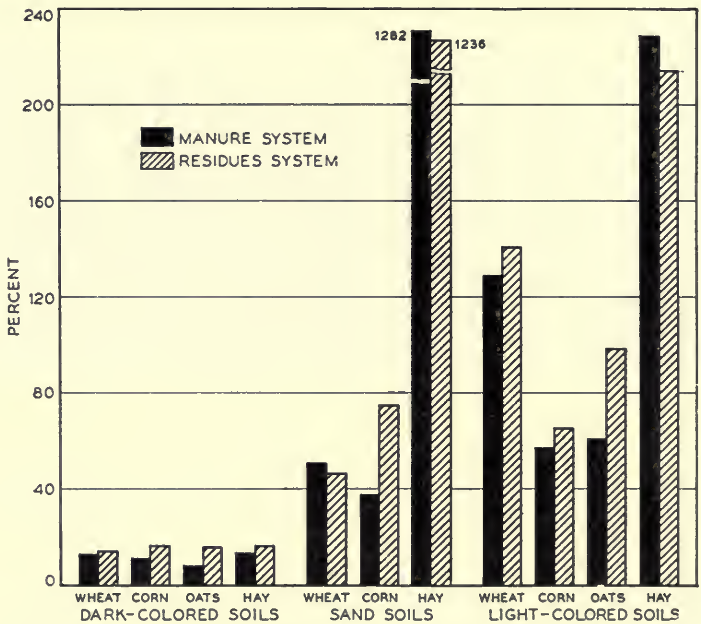

FIG. 13.—COMPARATIVE RESPONSE OF WHEAT, CORN, OATS, AND HAY TO LIMESTONE APPLICATIONS

On dark-colored soils the responses of the various kinds of crops have been somewhat similar, tho oats have tended to be the least responsive. All crops have been more responsive on sandy soils than on other soils, the hay crops being very responsive. On the light-colored soils the grain crops are much more responsive than on the other kinds of soil. Wheat is about twice as responsive as corn on these soils. The hay crops are highly responsive but less so than when grown on sandy soils.

limestone is recorded as a ratio between the limed and the unlimed yields. If the yield for the limed land is desired, it can be determined by multiplying the unlimed yield by the ratio figure. Thus if the yield of corn was 30 bushels an acre on unlimed land and the response ratio was 1.500, it would mean that the yield on the limed land was 45 bushels (30×1.500).

For all crops limestone has demonstrated its importance much more strikingly on the sandy and the light-colored soils than on the dark-colored soils. The hay crops are especially responsive on the sandy and the light-colored soils. The grain crops differ more in their response to limestone on these soils than they do on the dark-colored soils. Wheat, for example, is much more responsive than corn on the light-colored soils, but on the more productive dark-colored soils the difference is negligible. All crops, however, have given a rather small response to limestone on the dark-colored soils. Oats usually have given the smallest response of any of the nonlegume crops on these soils.

In general, crop responses to limestone have been greater in the residues system than in the manure system.

Responses of Legume Crops

The response of soybeans, common clovers, and alfalfa to limestone applications, in both the manure and residues systems, is shown in Tables 7 and 8. Since these legume crops were not grown regularly on all fields, it is impossible to make comparisons of their individual responses under all soil conditions, but nevertheless some interesting differences in these crops are to be observed.

Altho all the legumes grown on light-colored soils gave a remarkable response to liming, the common clovers gave a much more pronounced response than soybeans. The increase in the yield of the

FIG. 14.—LIMESTONE MEANS A BETTER FIRST-YEAR STAND OF RED CLOVER

Seeded in the spring with oats, red clover made very sparse growth on land where only manure was applied. The above pictures were taken in the fall of the first year. A year later the hay yield on the limed land was three-quarters of a ton larger than on the unlimed land. *Mt. Morris field, 1932.*

clovers varied from 300 to 465 percent, while that of the soybeans varied from 37 to 66 percent.

Legumes grown on the most productive fields gave but little response to limestone and varied little in their degrees of response. On the dark-colored soils of medium and low productivity (Groups IV, V, and VI) the various legumes showed rather striking differences in their response to limestone. Soybean increases varied from 4 to 10

FIG. 15.—LIMESTONE MAKES THE DIFFERENCE BETWEEN ALFALFA AND NO ALFALFA ON SANDY LAND

Limestone and alfalfa are an excellent combination for sandy land. Three and a quarter tons of good quality alfalfa hay was harvested where limestone and manure were applied. On land that received only manure, alfalfa failed completely. *Oquawka field, 1931.*

percent, while increases in the yields of the common clovers varied from 14 to 40 percent. On both the light-colored and the dark-colored soils the greatest increases were obtained in the residues system.

The variations in the responses of the various kinds of crops—legumes and nonlegumes—to limestone, are, no doubt, related to their lime requirements and the ease with which they are able to obtain the needed lime from the supplies naturally in the soil. The lime deficiencies in the dark-colored soils are not sufficient to cause a great deal of difference in the growth of the different kinds of crops except clover and alfalfa when grown on some of the least productive soils in these groups. In the sandy and the light-colored soils the available calcium or other lime materials and other nutrients are sufficiently low to cause somewhat more striking differences in the responses of the different crops.

TABLE 7.—MANURE SYSTEM: RESPONSE OF SOYBEANS, CLOVER, AND ALFALFA TO LIMESTONE ON ILLINOIS SOIL EXPERIMENT FIELDS
(Yields are given as annual acre averages)

Soil groups and fields in order of natural productivity	Soybean yields[1]			Clover yields[1 2]			Alfalfa yields[1]		
	No. of crops (1)	Manure only (2)	Ratio $\frac{ML}{M}$ (3)	No. of crops (4)	Manure only (5)	Ratio $\frac{ML}{M}$ (6)	No. of crops (7)	Manure only (8)	Ratio $\frac{ML}{M}$ (9)
I. *Dark soils with heavy, noncalcareous subsoils*		*tons*			*tons*			*tons*	
Hartsburg	2	1.64	1.110	6	2.40	1.042	10	3.67	1.065
LaMoille	1	2.20	.991	8	3.03	.993	11	2.55	1.008
Aledo	3	1.92	1.047	6	2.74	1.139	..	....	.....
Minonk	4	1.51	1.060	5	2.81	.975	..	....	.....
Average[3]	..	1.73	1.056	..	2.76	1.034	..	3.08	1.040
II. *Dark soils with noncalcareous subsoils*									
Kewanee	....	....	.....	14	2.24	1.053	..	....	.....
III. *Brownish-yellow soils with open, noncalcareous subsoils*									
Springvalley	1	2.47	1.032	13	2.67	1.026	8	3.30	1.142
IV. *Dark soils with open, noncalcareous subsoils*									
Mt. Morris	2	1.80	.978	15	2.40	1.204	12	2.33	1.601
Dixon	5	1.75	1.069	13	2.33	1.069	24	3.95	1.109
Average[3]	..	1.76	1.042	..	2.37	1.142	..	3.41	1.221
V. *Dark soils with impervious, calcareous subsoils*									
Joliet	6	1.51	1.086	12	1.45	1.159	13	1.35	1.437
VI. *Dark soils with impervious, noncalcareous subsoils*									
Carthage	5	2.12	1.000	14	2.30	1.213	..	....	.....
Clayton	5	1.84	1.087	14	2.13	1.324	..	....	.....
Lebanon	9	1.59	1.151	8	2.95	1.156	..	....	.....
Carlinville	4	1.76	1.142	11	2.00	1.635	..	....	.....
Average[3]	..	1.79	1.096	..	2.29	1.318	..	....	.....
VII. *Sandy loams and sands*									
Oquawka	17	1.03	1.146	2	.00	(3.52[4])	14	1.68	1.738
VIII. *Yellow soils with noncalcareous subsoils*									
Unionville	19	.95	1.537	..	....	.....	..	....	.....
Enfield	5	.59	2.169	2	.27	4.410	..	....	.....
Average[3]	..	.88	1.626	..	.27	4.410	..	....	.....
IX. *Gray soils with impervious, noncalcareous subsoils*									
Oblong	5	1.25	1.528	4	.46	2.696	..	....	.....
Toledo	3	.72	1.764	3	.24	3.250	..	....	.....
Raleigh	8	.91	1.516	9	.25	5.280	..	....	.....
Sparta	15	.69	1.826	1	.00	(1.66[4])	..	....	.....
Newton	17	.83	1.410	..	....	.....	..	....	.....
Ewing	8	.48	2.500	3	.23	4.565	..	....	.....
Average[3]	..	.79	1.655	..	.27	4.322	..	....	.....
X. *Hilly land*									
Elizabethtown	4	.50	1.480	..	....	.....	6	.10	11.900

[1]Yields on the limed land can be determined by multiplying the yields on the unlimed land by their response ratios. [2]Mostly red clover. [3]Weighted averages. [4]Actual yield for limestone.

TABLE 8.—RESIDUES SYSTEM: RESPONSE OF SOYBEANS, CLOVER, AND ALFALFA TO LIMESTONE ON ILLINOIS SOIL EXPERIMENT FIELDS
(Yields are given as annual acre averages)

Soil groups and fields in order of natural productivity	Soybean yields[1]			Clover yields[1]			Alfalfa yields[1]		
	No. of crops (1)	Residues only (2)	Ratio RL/R (3)	No. of crops (4)	Residues only (5)	Ratio RL/R (6)	No. of crops (7)	Residues only (8)	Ratio RL/R (9)
I. *Dark soils with heavy, noncalcareous subsoils*		*bu.*			*tons*			*tons*	
Hartsburg	3	25.4	1.024	6	1.78	.955	10	3.78	.913
LaMoille	2	17.2	1.035	8	1.94	1.041	..	....	.....
Aledo	4	16.0	1.062	6	1.91	.937	..	....	.....
Minonk	5	18.6	.952	5	1.50	1.007	..	....	.....
Average[2]	..	19.1	1.009	..	1.81	.989	..	3.78	.913
II. *Dark soils with noncalcareous subsoils*									
Kewanee	..	....	.....	14	1.38	1.174	..	....	.....
III. *Brownish-yellow soils with open, noncalcareous subsoils*									
Springvalley	1	22.8	.991	13	2.33	1.030	..	....	.....
IV. *Dark soils with open, noncalcareous subsoils*									
Mt. Morris	2	16.0	1.181	15	1.57	1.306	..	....	.....
Dixon	6	14.0	1.014	13	1.48	1.176	..	....	.....
Average[2]	..	14.5	1.060	..	1.53	1.247	..	....	.....
V. *Dark soils with impervious, calcareous subsoils*									
Joliet	11	13.1	1.092	12	.97	1.155	13	1.12	1.393
VI. *Dark soils with impervious, noncalcareous subsoils*									
Carthage	5	23.7	.932	14	1.36	1.360	..	....	.....
Clayton	5	17.6	1.125	14	1.48	1.385	..	....	.....
Lebanon	10	14.0	1.086	8	1.48	1.344	..	....	.....
Carlinville	4	17.6	1.290	11	1.83	1.497	..	....	.....
Average[2]	..	17.4	1.085	..	1.53	1.403	..	....	.....
VII *Sandy loams and sands*									
Oquawka	18	8.5	1.435	2	.00	(2.13[3])	14	1.36	2.147
VIII. *Yellow soils with noncalcareous subsoils*									
Unionville	20	5.9	1.441	..	....	.....	..	....	.....
Enfield	6	3.8	2.500	2	.17	4.765	..	....	.....
Average[2]	..	5.4	1.612	..	.17	4.765	..	....	.....
IX. *Gray soils with impervious, noncalcareous subsoils*									
Oblong	6	10.5	1.495	4	.60	2.650	..	....	.....
Toledo	5	5.3	1.830	3	.15	7.267	..	....	.....
Odin	26	8.2	1.268	..	....	.....	..	....	.....
Raleigh	8	5.7	2.123	9	.08	8.875	..	....	.....
Sparta	13	4.9	2.367	1	.00	(1.50[3])	..	....	.....
Newton	18	5.4	1.611	..	....	.....	..	....	.....
Ewing	8	3.4	2.823	3	.00	(.88[3])	..	....	.....
Average[2]	..	6.4	1.667	..	.18	5.647	..	....	.....
X. *Hilly land*									
Elizabethtown	5	2.7	1.370	..	....	.....	6	.02	34.000

[1]Yields on the limed land can be determined by multiplying the yields on the unlimed land by their response ratios. [2]Weighted averages. [3]Actual yield for limestone.

That the various crops have made less pronounced responses to limestone in the manure system than in the residues system is due to the effect of the manure in reducing deficiencies of lime and other plant nutrients.

EFFECT OF LIMESTONE ON SOIL PRODUCTIVITY LEVELS

The soils upon which the different experiment fields are located vary greatly in natural productiveness (Table 1). The more productive soils yield, on the average, more than a ton and a quarter of grain and hay an acre annually, corn alone averaging about 50 bushels an acre. The poorest soils are only about one-tenth as productive. The Elizabethtown field, for instance, produces on the average only 325 pounds of grain and hay an acre annually and 11.5 bushels of corn. The other soils produce yields distributed more or less uniformly between these extremes.

Whether the level of productivity of the poorer soils can be raised to that of the naturally more productive soils by means of good management and treatment practices is a question of very practical interest. The direct influence of limestone on the productive levels of the different soils is shown in Table 9 and also in Tables 1 and 4. The fields in Soil Group I are used as the standard of reference. The annual crop yields of the untreated land in this group have averaged 2,477 pounds an acre. The field representing Group X, the least productive group, has produced only 325 pounds an acre, or 13.1 percent as much as the average in Group I. The ratio is then .131. The total yields from the limestone plots in both the manure and the residues systems divided by 2,477 provide ratios (Columns 4 and 6) which indicate directly the influence that limestone has had in raising the productivity levels of the various soils toward the levels of the naturally more productive soils. The results for the different soil groups are shown graphically in Fig. 16.

Limestone has raised the productivity levels of all soils. It has shown the least influence on the naturally more productive soils and the greatest influence on the naturally less productive soils. The handicap on the least productive soils, however, is so great that the present levels are far from approaching the natural levels of the more productive soils. The light-colored soils have, under treatment, reached production levels that are approximately 50 percent as high as the levels of the naturally more productive soils. Groups II, III, and IV,

representing the more productive dark-colored soils, are the only groups whose levels have been raised to that of Group I, the standard used. On the dark-colored soils limestone used in the residues system tended to be more effective than in the manure system. This tendency, however, was reversed on the sandy and the light-colored soils.

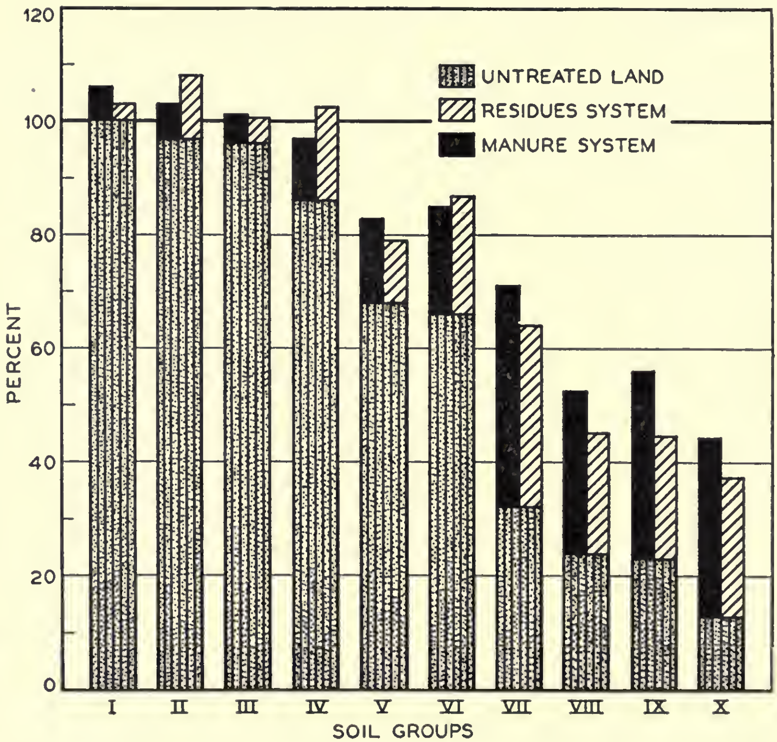

FIG. 16.—INFLUENCE OF LIMESTONE ON PRODUCTIVITY LEVELS OF VARIOUS ILLINOIS SOILS

The productivity levels of Groups II to X, compared with that of Group I, the naturally most productive soils, without soil treatment, are shown by the lower portions of the bars. The influence that limestone has had in raising the productivity levels of these soils, both in the manure and in the residues systems of farming, is shown by the upper parts of these bars. Limestone raised the level of every group, Groups II, III, and IV reaching the 100-percent level. The least productive soils were raised approximately to 50 percent of the level of the most productive soils.

Thus limestone has had striking effects in raising the productive levels of some soils, but it has not been able to bring all soils to the same level.

TABLE 9.—INFLUENCE OF LIMESTONE ON PRODUCTIVE LEVELS OF ILLINOIS SOILS

Soil groups and fields in order of natural productivity	Untreated land		Limed land			
			Manure system		Residues system	
	Average yield (1)	Productivity ratio[1] (2)	Yield (3)	Productivity ratio[1] (4)	Yield (5)	Productivity ratio[1] (6)
I. *Dark soils with heavy, noncalcareous subsoils*	*lbs.*		*lbs.*		*lbs.*	
Hartsburg	2 600	1.050	2 916	1.177	2 548	1.029
LaMoille	2 524	1.019	2 547	1.028	2 670	1.078
Aledo	2 396	.967	2 702	1.098	2 615	1.056
Minonk	2 388	.964	2 378	.960	2 382	.962
Average	2 477	1.000	2 636	1.064	2 554	1.031
II. *Dark soils with noncalcareous subsoils*						
Kewanee	2 408	.972	2 546	1.028	2 670	1.078
III. *Brownish-yellow soils with open, noncalcareous subsoils*						
Springvalley	2 372	.958	2 494	1.007	2 484	1.003
IV. *Dark soils with open, noncalcareous subsoils*						
Mt. Morris	2 210	.892	2 527	1.020	2 747	1.109
Dixon	2 068	.835	2 283	.922	2 331	.941
Average	2 139	.863	2 405	.971	2 539	1.025
V. *Dark soils with impervious, calcareous subsoils*						
Joliet	1 690	.682	2 045	.826	1 946	.786
VI. *Dark soils with impervious, noncalcareous subsoils*						
Carthage	1 748	.706	2 117	.855	2 222	.897
Clayton	1 723	.696	2 185	.882	2 279	.920
Lebanon	1 661	.670	1 941	.784	2 075	.838
Carlinville	1 476	.596	2 170	.876	2 014	.813
Average	1 652	.667	2 103	.849	2 147	.867
VII. *Sandy loams and sands*						
Oquawka	799	.322	1 747	.705	1 593	.643
VIII. *Yellow soils with noncalcareous subsoils*						
Unionville	684	.276	1 148	.463	1 124	.454
Enfield	494	.199	1 418	.572	1 131	.457
Average	589	.238	1 283	.518	1 128	.455
IX. *Gray soils with impervious, noncalcareous subsoils*						
Oblong	731	.295	1 511	.610	1 238	.500
Toledo	611	.247	1 403	.566	1 228	.455
Odin	608	.246	.....	.....	872	.352
Raleigh	558	.225	1 442	.582	1 241	.501
Sparta	527	.213	1 248	.504	1 010	.408
Newton	500	.202	1 179	.476	969	.391
Ewing	482	.194	1 506	.608	1 150	.464
Average	574	.232	1 381	.558	1 101	.444
X. *Hilly land*						
Elizabethtown	325	.131	1 091	.440	934	.377

[1]The ratio representing the productive level of a field is obtained by dividing the average annual acre-yield by 2,477, the average yield (in pounds) of the more productive soils (Group I).

RAPIDITY AND TREND OF RESPONSE TO LIMESTONE

In the preceding pages the discussion dealt with the influence of limestone on crop yields as revealed by data massed into rather broad averages—averages for all the years since limestone applications were started. Data massed in this way reveal certain outstanding facts, but they do not show how quickly crop increases were obtained on the different fields and soils, nor whether such increases became greater, remained the same, or diminished with the passage of time—matters of very great importance to all interested in the use of limestone for soil-improvement purposes.

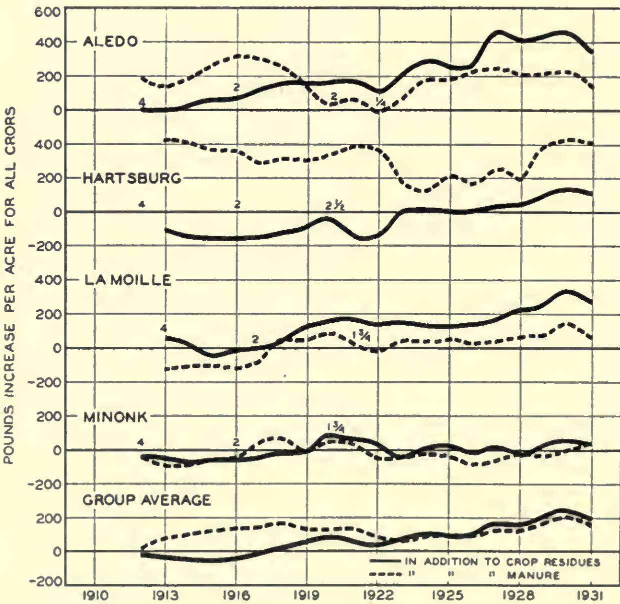

FIG. 17.—TREND OF LIMESTONE INFLUENCE ON DARK SOILS WITH HEAVY, NONCALCAREOUS SUBSOILS, GROUP I

There is some evidence that limestone has tended to be of a little more value in recent years than in the earlier years of these experiments.

In order to ascertain the rapidity and the trend of the response to limestone exhibited by different soils under different systems of farming, the yearly increases in crop yields on the various fields under the manure and residues systems of farming have been converted into movable rotation averages and plotted into the graphs shown in

Figs. 17 to 22. Since a four-year rotation is practiced on most fields, the figure for any particular year is the average of sixteen crop harvests. The small figures along the zero line in the trend charts for each individual field represent tons of limestone applied for that field and approximate time of application. The total tonnage of limestone for each field can be determined by adding together the figures given for that field.

Dark Soils With Heavy, Noncalcareous Subsoils

The rapidity and the trend of the response to limestone on the fields in the most productive soil groups—the dark soils with heavy, noncalcareous subsoils (Group 1)—have not been striking (Fig. 17).

The best response has been obtained on the Aledo field, especially in the residues system, where the crop increases resulting from limestone applications have tended to become gradually larger. The Minonk field has never given much response to limestone. On all fields except the one at Hartsburg better responses have been obtained in the residues system than in the manure system. No reason has been discovered for the peculiar behavior of the Hartsburg field.

When the responses for all fields are averaged together for each year, there is a slight tendency for the later years to show the greater response. This increasing response suggests that these soils are becoming deficient in lime, and that with continued cultivation of this land limestone may come to be of more and more importance.

Dark Soils With Open, Noncalcareous Subsoils

On the Mt. Morris and the Dixon fields, representing the dark soils with open, noncalcareous subsoils (Group IV), the increases from the use of limestone were rather small during the earlier years these fields were under test (Fig. 18). After the first two rotations, however, there were pronounced increases in yields, which were maintained for about twelve years. For the last three or four years there has been a falling off in response, indicating either the need for further applications of limestone or an increasing deficiency of some other nutrient. Field tests show no deficiency of lime.

As in Group I, the dark soils with heavy, noncalcareous subsoils, the greatest responses to limestone have been obtained in the residues system.

Dark Soils With Impervious, Noncalcareous Subsoils

Steadily increasing yields from the use of limestone were obtained on the Carthage, Clayton, Lebanon, and Carlinville fields, representing

the dark soils with impervious, noncalcareous subsoils (Group VI), for the first fifteen or sixteen years these fields were under test (Fig. 19). For the last six or seven years, however, increases in yield have tended to remain stationary on some fields and on others have declined.

On three fields—Carthage, Clayton, and Lebanon—the largest increases have been obtained in the residues system. During recent years, however, the manure and residues systems have tended to become about equally effective. In fact, on the Clayton field in 1931 the response in the manure system was slightly higher than in the residues system. On the Carlinville field the advantage has always been with the manure system. On this field, the soil of which is in a later stage of development than that of the other three fields (see Table 1), manure is evidently supplying a deficiency that is becoming more and more pronounced and that cannot be cared for in the residues system. Experiments on the Carlinville field indicate that this deficiency may be potassium.

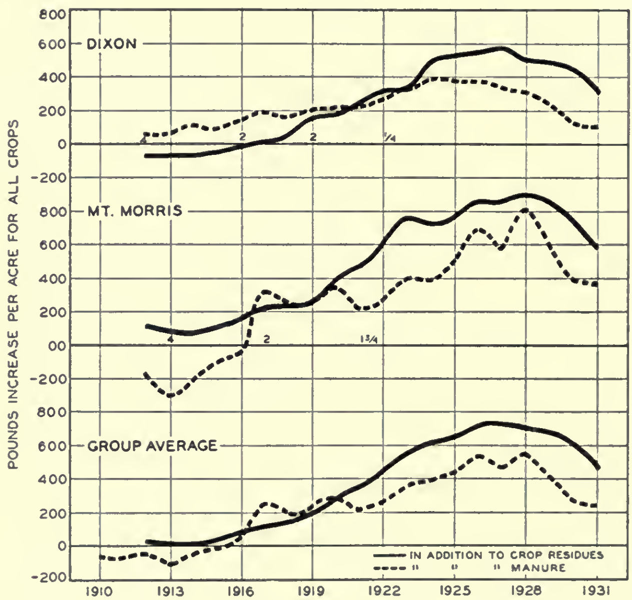

FIG. 18.—TREND OF LIMESTONE INFLUENCE ON DARK SOILS WITH NONCALCAREOUS SUBSOILS, GROUP IV

The response to limestone was low in the early years. It became increasingly larger in later years, reaching the crest of its influence after about sixteen years, since which time it has been slowly receding.

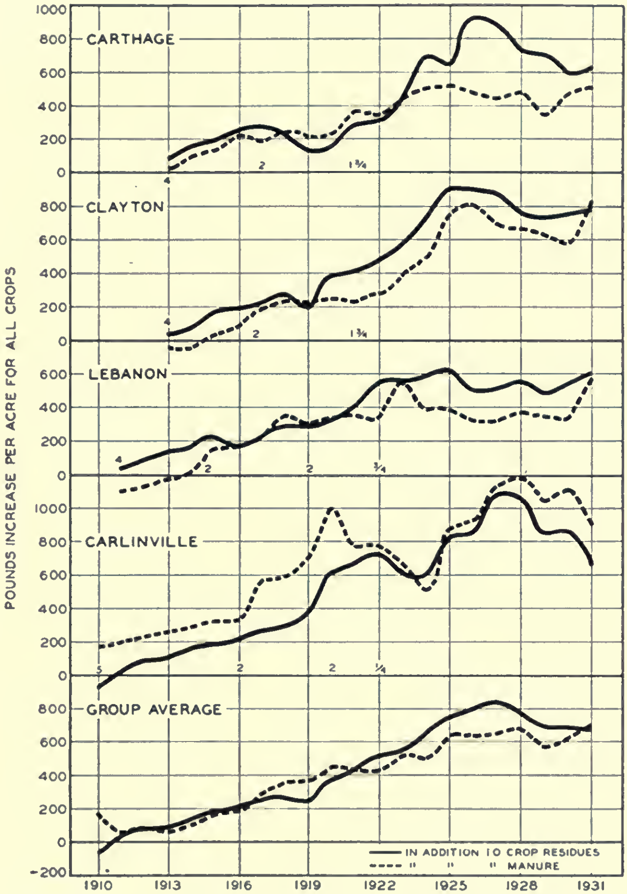

FIG. 19.—TREND OF LIMESTONE INFLUENCE ON DARK SOILS WITH IMPERVIOUS, NONCALCAREOUS SUBSOILS, GROUP VI

More or less regular increases in crop yields have occurred on the fields in this soil group since the beginning of the limestone applications. Limestone reached the crest of its influence about eighteen years after the first application, since which time it has gradually declined.

Yellow Soils With Noncalcareous Subsoils

The Enfield and Unionville fields, representing the yellow soils with noncalcareous subsoils (Group VIII), have shown quite different responses to limestone (Fig. 20).

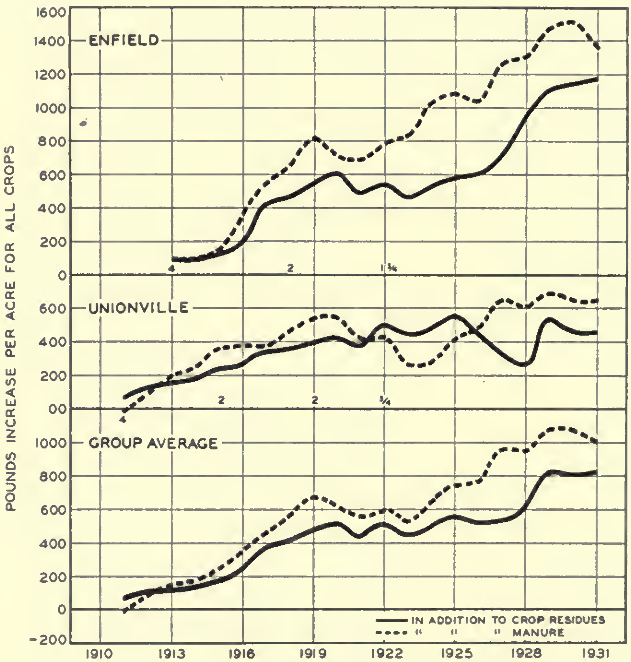

FIG. 20.—TREND OF LIMESTONE INFLUENCE ON YELLOW SOILS WITH NONCALCAREOUS SUBSOILS, GROUP VIII

The Enfield field has shown a rapidly increasing response to limestone thruout practically the twenty years of test. The Unionville field showed a gradually increasing response during the first years, but during the last fifteen years the response has remained practically stationary.

The differences between these fields in their responses to limestone are doubtless due to differences in certain soil characteristics. The Unionville field is located close to the Ohio river in Massac county on comparatively low land, whereas the Enfield field is away from the river on higher land.

On both fields better responses to limestone have appeared in the manure system than in the residues system.

Gray Soils With Impervious, Noncalcareous Subsoils

Fairly rapid and increasing responses to limestone have been shown by the gray soils with impervious, noncalcareous subsoils (Group IX), represented by seven fields—the Ewing, Oblong, Newton, Odin,

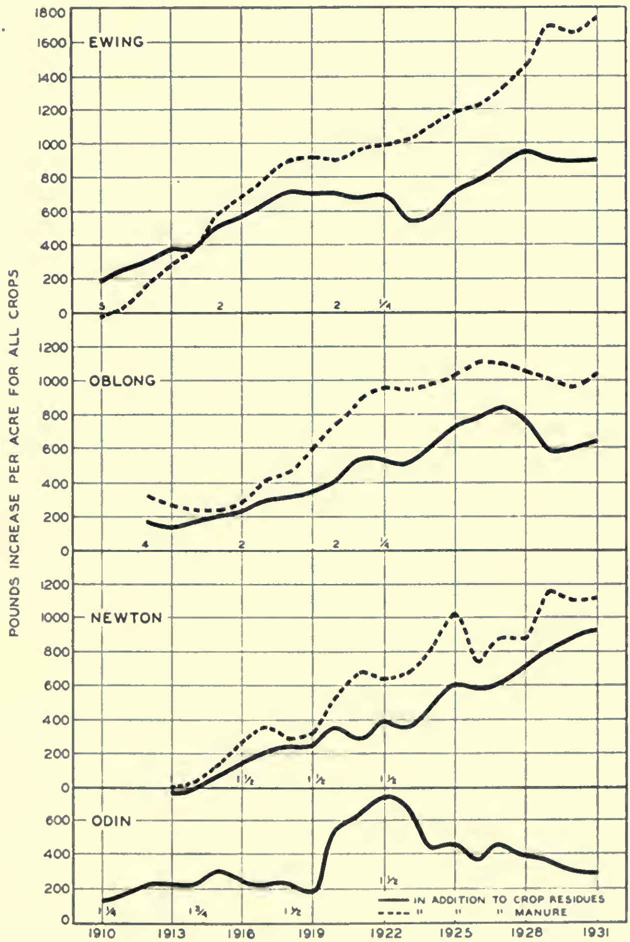

FIG. 21.—TREND OF LIMESTONE INFLUENCE ON GRAY SOILS (GROUP IX)

Raleigh, Toledo, and Sparta fields (Fig. 21). The Ewing field has given the most striking response, the Odin field the least striking.

The greatest responses have occurred in the manure system,

especially on the Ewing field, where the trend has been upward with no indication that the limit of response has been reached. In the residues system on the Ewing field a rapidly increasing response to

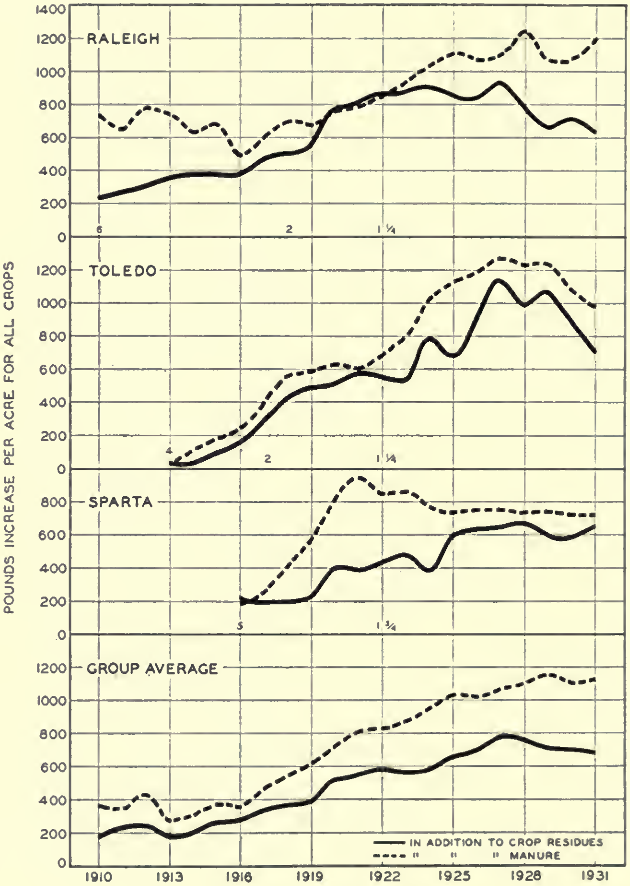

FIG. 21.—CONCLUDED

On the whole the fields representing this soil group have shown a rapid upward trend in their response to limestone applications. In all groups limestone has been decidedly more effective when used with manure than when used with crop residues. Some fields are continuing to show increasing response; some are leveling out; and some are declining.

limestone occurred during the first eight years, since which time there has been but little change in the response level.

On the other fields in this group the differences between the manure and the residues systems in their responses to limestone are

similar to the differences on the Ewing field. Other experiments on these fields indicate that there may be a deficiency of potash, a deficiency that manure would help to correct. If the manure system had been used on the Odin field, the results would probably have been similar to those in the manure system on the Ewing field.

On the whole, limestone has proved of great importance to the soils in this group.

Other Soils Represented by Single Fields

The limestone responses for each of the five soil groups represented by only one field are shown in Fig. 22.

The dark-colored soils, represented by the Joliet, Kewanee, and Springvalley fields, have given relatively small responses to limestone. On the Springvalley field there have been practically no crop increases, while on the Joliet and Kewanee fields there have been slowly increasing yields.

The sandy and the hilly lands, represented by the Oquawka and Elizabethtown fields, have given very favorable responses to limestone. This is especially true of the sandy Oquawka field, which, during the first eight years of the test, gave the most rapid response of all the fields studied. During the last nine years crop yields have tended to remain stationary or to decline slightly, suggesting that limestone is possibly decreasing in its effectiveness. The hilly land at Elizabethtown also responded very rapidly at first to limestone applications, but here too, after eight years, crop yields have tended to remain stationary or to decline.

General Discussion of Response Trends

As indicated in the foregoing graphs, different soils vary considerably in the rapidity of their response to limestone and in the degree of their response. The more productive, dark-colored soils (Group I), on the whole, have given rather small increases in crop yields as a result of limestone applications. Two fields in this group that produced good crops for many years without showing much response to limestone have begun to give increased yields for limestone, a fact which indicates that they are becoming lime-deficient. From now on they are likely to give increasing responses to limestone.

On all the other dark-colored soils the crop increases in recent years have tended to remain stationary and on some fields even to decline. This slowing up of response may hint that other nutrients are becoming deficient and that such deficiencies are interfering with

the effects of limestone. That other nutrients are becoming deficient in the dark-colored soils is indicated by the differences in response to limestone in the manure and in the residues systems. On the more productive dark-colored soils the response in the residues system has

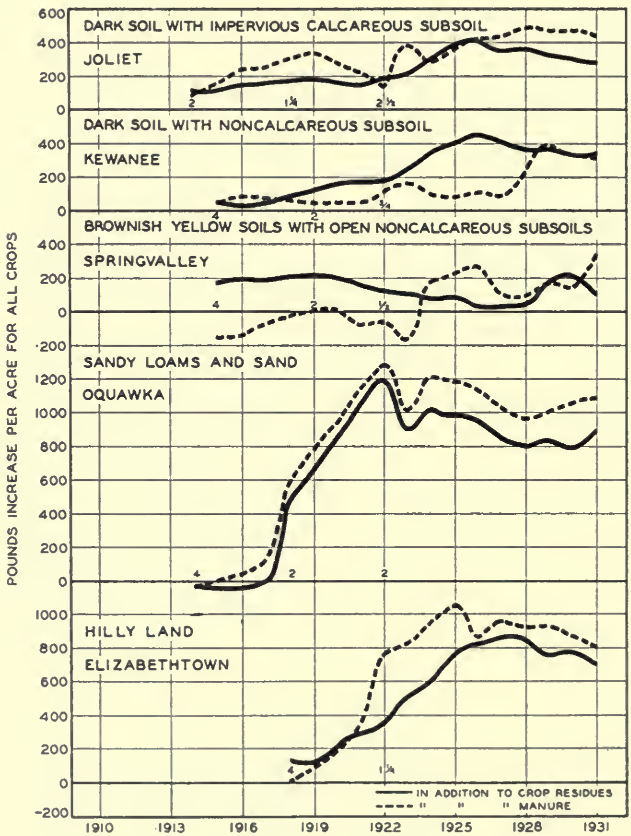

FIG. 22.—TREND OF LIMESTONE INFLUENCE ON SOIL GROUPS REPRESENTED BY A SINGLE FIELD

No very definite responses have been exhibited by the Joliet, Kewanee, and Springvalley fields, representing Groups II, III, and V. The Oquawka and Elizabethtown fields, representing Groups VII and X, however, showed rather rapid response for the first ten years, and these responses reached rather high levels.

been as great as that in the manure system, or greater. On the less productive dark-colored soils the advantage in favor of the residues system has tended to disappear. On the sandy and the light-colored soils the advantages have been decidedly in favor of the manure sys-

tem. Evidently the legume-limestone system of soil management is not so effective in meeting the requirements of the less productive soils as is the manure-limestone system. Deficiencies in phosphorus or potassium, or both, are met in part at least by the manure applied. Tho nutrients other than phosphorus and potassium may also be involved, experiments indicate that on some fields—Joliet and Elizabethtown, for example—the deficient element probably is phosphorus. On the light-colored soils, such as those represented by the Ewing, Toledo, and other fields, there is apparently a deficiency of potassium. Where either deficiency exists, the effectiveness of limestone is likely to be reduced until the deficiency is corrected.

Lasting Effects of Single Applications of Limestone

The West Salem field (a mature yellow soil with noncalcareous subsoil, Group VIII), not represented in the above summaries, provides data that show the long-time response that may result from a single application of limestone. In 1912 limestone at the rate of 4

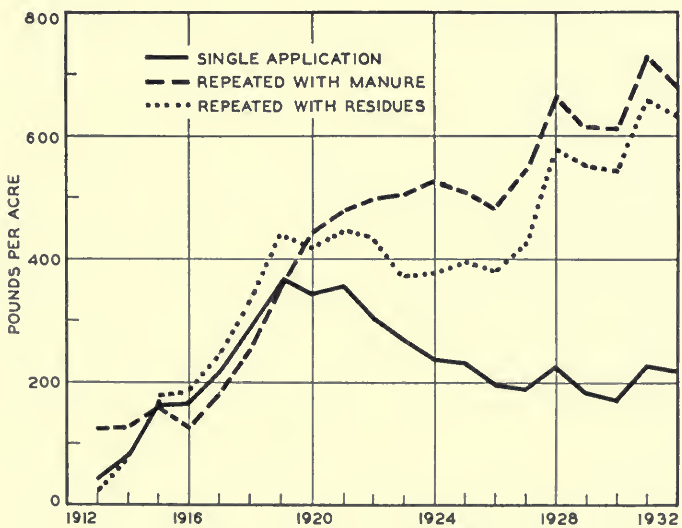

FIG. 23.—LASTING EFFECTS OF A SINGLE APPLICATION OF LIMESTONE AS SHOWN BY INCREASES IN CROP YIELDS

A 4-ton application of limestone was made to certain plots on the West Salem field in 1912. One of these plots received no further limestone. The greatest increase in crop yields on this plot occurred in 1919, the eighth year after the limestone application, and it is apparent that this one application is still having an effect. The crops grown were corn, oats, wheat, and hay in rotation.

tons an acre was applied to each of three plots that were originally designed for crop production without limestone. One of these plots has never received any further treatment; another has received manure only; and a third has received crop residues only. Similar plots receiving regular applications of limestone were maintained alongside the above plots until 1923, when limestone applications were temporarily discontinued on all plots.

The lasting effect of a single application of limestone without manure or residues, over a twenty-year period, is indicated by the solid line in Fig. 23. The single application steadily increased crop yields until the eighth year. During the eighth and ninth years the increases remained about stationary, but after the ninth year they grew steadily smaller. After twenty years, however, there is still evidence of a decided influence from the single application of limestone.

The repeated applications of limestone in the manure and residues systems showed little superiority over the single application until the eighth year, after which they gave much better results. Apparently a second application of limestone to soils of this type is not needed until about eight years after the initial application.

The increases in yields resulting from the repeated applications of limestone, even tho none have been made since 1923, still show a steady upward trend.

Response Trends as Related to Total Yields

In studying only the spreads between total yields on treated land and total yields on comparable untreated land the question arises whether the differences are the result of definite improvement in the productive level of the treated land or of the declining productivity of the untreated land. This question is answered in Fig. 24 for two groups of Illinois soils—Group VI, the dark soils with impervious, noncalcareous subsoils, and Group IX, the gray soils with impervious, noncalcareous subsoils.

The increases arising from the application of limestone to these soils were, without exception, the result of improved crop yields on the limed land and not of declining yields on the unlimed land. On some fields the yields from the unlimed land tended to remain about the same year after year; on other fields they tended to become larger but at a slower rate than those obtained from the limed land. On no field was there any tendency for the yields on the limed land to remain stationary while the yields on the unlimed land declined, nor was there any tendency for the yields on the limed land to decline but at a slower rate than on the unlimed land. These statements are also de-

scriptive of the action of limestone on the fields in the other soil groups studied.

Thus the role of limestone in soil management takes on further significance when it is demonstrated that it makes a positive contribution to soil productivity rather than merely retarding the process of fertility decline.

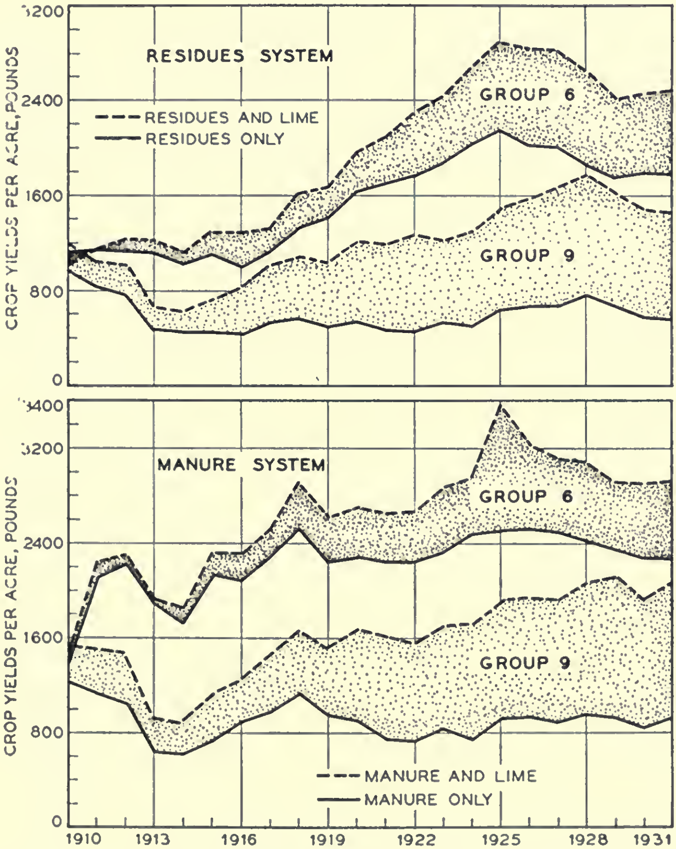

FIG. 24.—CROP YIELDS ON LIMED AND UNLIMED PLOTS OF TWO GROUPS OF SOILS UNDER THE MANURE AND CROP RESIDUES SYSTEMS OF TREATMENT

That the increases in yields credited to limestone applications on the fields in the above soil groups are the result of definite improvement in yields on the limed land is evident from the fact that the yields on the unlimed land have shown no special tendency to decline. Group VI represents the dark soils with impervious, noncalcareous subsoils, and Group IX the gray soils with the same kind of subsoil.

ECONOMIC RESPONSES TO LIMESTONE

The effects of limestone on various soils, as measured by crop responses, have been shown in the preceding pages without reference to the economic value of such response. A farm practice that has scientific interest is not, however, generally adopted until it becomes clear that it is also economically worth while—that is, that it will return a satisfactory margin of profit above all costs.

Attempts to generalize concerning the net returns from a given soil treatment over a period of years in such a way that the statements have meaning for individual farms are beset with many difficulties. Money values must be used, and yet not only are crop prices constantly changing but they vary in different localities, and purchase prices, interest rates, costs of hauling and distributing, and costs of harvesting and marketing the increases in yield vary from farm to farm. Any figures that result from the application of money values to costs and returns must therefore be considered only general indexes of the probable meaning of the practice to an individual farmer. A farmer must refigure costs and returns in accordance with his own experiences before he can know, with a satisfactory degree of accuracy, the value of a practice to him.

Because prices have varied so widely in recent years, three levels of crop prices are used in interpreting, in terms of money values, some of the crop-yield data obtained in these experiments. They represent the average of the higher prices that have prevailed, of medium prices, and of lower prices, as follows:

	Higher prices	Medium prices	Lower prices
Wheat	$ 1.25	$ .88	$ .50
Corn	.70	.49	.28
Oats	.40	.28	.16
Hay	12.50	8.75	5.00

Acre-Values of Crop Increases

The value of the increases in crop yields resulting from the use of limestone on Illinois soils, at three levels of crop prices, is indicated in Table 10.

For most fields approximately two-fifths of a ton, or 800 pounds of limestone (Column 2), may be charged against the annual acre-value of the crop increases. If this amount of limestone should cost around $1.50 applied to the soil, then applications of limestone on the most productive soils (Group I) have not been profitable at any of the

TABLE 10.—AVERAGE ANNUAL ACRE-VALUES OF CROP INCREASES RESULTING FROM USE OF LIMESTONE ON ILLINOIS SOILS
(At three levels of prices[1])

Soil groups and fields in order of natural productivity	Limestone applied		Value of crop increases in *manure* system			Value of crop increases in *residues* system		
	Total amount (1)	Annual rate (2)	At *higher* crop prices (3)	At *medium* crop prices (4)	At *lower* crop prices (5)	At *higher* crop prices (6)	At *medium* crop prices (7)	At *lower* crop prices (8)
I. *Dark soils with heavy, noncalcareous subsoils*	*tons*	*tons*						
Hartsburg	8.50	.42	$3.89	$2.72	$1.55	$ −.30	$ −.21	$ −.12
LaMoille	7.75	.41	.17	.12	.07	1.89	1.32	.75
Aledo	8.25	.41	1.96	1.37	.79	3.13	2.19	1.25
Minonk	8.25	.41	−.26	−.18	−.10	−.62	−.43	−.25
Average	8.19	.41	1.44	1.01	.58	1.02	.71	.41
II. *Dark soils with noncalcareous subsoils*								
Kewanee	6.75	.40	1.67	1.17	.67	2.72	1.90	1.09
III. *Brownish-yellow soils with open, noncalcareous subsoils*								
Springvalley	6.75	.40	1.07	.75	.43	1.59	1.11	.63
IV. *Dark soils with noncalcareous subsoils*								
Mt. Morris	7.75	.41	4.24	2.97	1.70	6.48	4.54	2.59
Dixon	8.25	.41	2.46	1.72	.99	3.02	2.11	1.21
Average	8.00	.41	3.35	2.34	1.34	4.75	3.32	1.90
V. *Dark soils with impervious, calcareous subsoils*								
Joliet	7.40	.41	3.62	2.53	1.45	2.84	1.99	1.13
VI. *Dark soils with impervious, noncalcareous subsoils*								
Carthage	7.75	.41	4.03	2.82	1.61	5.43	3.80	2.17
Clayton	7.75	.41	4.61	3.23	1.85	5.54	3.88	2.21
Lebanon	8.75	.42	4.06	2.84	1.62	6.12	4.28	2.45
Carlinville	9.25	.42	6.47	4.53	2.59	5.72	4.00	2.29
Average	8.37	.41	4.79	3.35	1.92	5.70	3.99	2.28
VII. *Sandy loams and sands*								
Oquawka	7.90	.44	8.79	6.15	3.51	9.06	6.34	3.63
VIII. *Yellow soils with noncalcareous subsoils*								
Unionville	8.75	.42	6.63	4.64	2.65	6.90	4.83	2.76
Enfield	7.75	.41	9.33	6.53	3.73	8.69	6.08	3.48
Average	8.25	.41	7.98	5.59	3.19	7.80	5.46	3.12
IX. *Gray soils with impervious, noncalcareous subsoils*								
Oblong	8.25	.41	7.45	5.21	2.98	6.41	4.49	2.56
Toledo	7.25	.38	8.39	5.87	3.36	7.85	5.50	3.14
Odin	8.90	.30	....	....	....	5.04	3.53	2.02
Raleigh	9.25	.42	9.15	6.40	3.66	7.94	5.56	3.17
Sparta	6.75	.42	8.78	6.15	3.51	9.39	6.57	3.75
Newton	5.50	.29	8.35	5.85	3.34	6.18	4.33	2.48
Ewing	9.25	.42	11.19	7.83	4.47	9.91	6.94	3.96
Average	7.88	.38	8.89	6.22	3.55	7.53	5.27	3.01
X. *Hilly land*								
Elizabethtown	5.25	.37	8.34	5.84	3.34	8.01	5.61	3.20

[1]See page 346.

price-levels used. At the higher crop prices the use of limestone in the manure system has given sufficiently large crop increases to cover this investment, but the margins left to cover the costs of harvesting and marketing the increases in yields and other costs are too small to make the use of limestone profitable on such soils as a group. On the Hartsburg field in the manure system and on the Aledo field in the residues system sufficiently large increases were obtained to justify the use of limestone.

On some fields the application of limestone has been a paying practice at the higher crop prices but not at the lower prices. In general, however, all the least productive dark-colored soils, the sandy

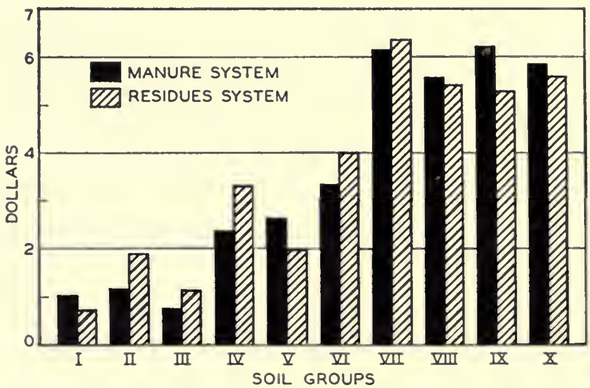

FIG. 25.—ACRE-VALUES OF CROP INCREASES WITH LIMESTONE

The various soil groups in the above chart are arranged in descending order of natural productivity. As productivity decreases from one group to another, the acre-value of the crop increases obtained from the use of limestone usually become larger. This tendency for crop increases to grow larger as productivity grows less is not so striking, however, for the sandy and light-colored silt loam soils, all of them giving about the same response regardless of their different natural productivity levels. Evidently there are limits of productivity beyond which it is practically impossible to obtain greater increases for limestone. (*Based on medium crop prices.*)

soils, and the light-colored soils have given sufficient increases in crop yields at all price-levels to pay for all additional costs resulting from the use of limestone. The sandy soils and some of the gray soils have given especially favorable economic responses. On the Ewing field in the gray group, for example, the value of the crop increases from limestone in the manure system at the lower prices has averaged nearly $4.50 an acre annually. Such returns should cover all costs involved in the use of limestone and provide a satisfactory profit from its use.

The values of the annual crop increases from limestone, calculated on the basis of the medium crop prices, are shown graphically in Fig. 25 for all the different soils and for both the manure and the residues systems.

On the dark-colored soils the residues system gave the greater increase in crop values, while on the light-colored soils the manure system gave the greater increases. The superiority of the manure system on the light-colored soils, as already pointed out, is no doubt due to the value of the manure in correcting certain soil deficiencies that do not exist on the dark-colored soils.

Since, as previously shown, the increases that have resulted from limestone, considering all fields and all soil groups, have been, in general, progressively larger from field to field with a decrease in the natural productive levels of these fields, the money values of the crop increases would naturally vary in the same way. Attention is also called again to the fact that in the three soil groups with the lowest productive levels there was little difference in the returns from limestone.

Ton-Values of Limestone as Measured by Value of Crop Increases

The value of the increases in crop yields resulting from each ton of limestone used upon the different experiment fields is indicated in Table 11. The values are based on the three different price-levels stated on page 346.

The ton-values of limestone vary greatly on different soils. At the lower prices for crops the average value of a ton of limestone used in the residues system on the more productive dark-colored soils stands at $1.00. On the least productive soils it has proved more than nine times as great as on the more productive dark-colored soils. At the higher prices in the residues system it varies from $2.50 to more than $23 a ton. On the Newton field in the manure system it reaches $28.85. These figures are long-time averages. Values for the last rotation period would be somewhat larger, as is indicated by some of the charts on pages 334-345.

The use of limestone has resulted in a margin of return above its cost on most soils. If the average purchase, hauling, and distributing costs should fall somewhere between $3 and $4 a ton, the average values of the increases in crop yields resulting from each ton of limestone used would be more than ample to cover all costs involved and still leave a good margin for its use on many fields. Even at the lower prices for crops there is a margin of profit on the majority of

TABLE 11.—VALUES OF CROP INCREASES PER TON OF LIMESTONE USED IN ILLINOIS FIELD EXPERIMENTS
(At three levels of crop prices[1])

Soil groups and fields in order of natural productivity	Total lime-stone applied (1)	Number of years in-volved (2)	Ton-values of limestone in *manure* system: At *higher* crop prices (3)	At *medium* crop prices (4)	At *lower* crop prices (5)	Ton-values of limestone in *residues* system: At *higher* crop prices (6)	At *medium* crop prices (7)	At *lower* crop prices (8)
I. *Dark soils with heavy, noncalcareous subsoils*	*tons*							
Hartsburg	8.50	20	$9.14	$6.40	$3.66	$−.71	$−.50	$−.29
LaMoille	7.75	19	.42	.29	.17	4.62	3.23	1.85
Aledo	8.25	20	4.76	3.33	1.90	7.58	5.31	3.03
Minonk	8.25	20	−.62	−.43	−.25	−1.50	−1.05	−.60
Average	8.19	..	3.42	2.39	1.37	2.50	1.75	1.00
II. *Dark soils with noncalcareous subsoils*								
Kewanee	6.75	17	4.20	2.94	1.68	6.85	4.80	2.74
III. *Brownish-yellow soils with open, noncalcareous subsoils*								
Springvalley	6.75	17	2.70	1.89	1.08	4.01	2.81	1.60
IV. *Dark soils with open, noncalcareous subsoils*								
Mt. Morris	7.75	19	10.41	7.29	4.17	15.58	10.91	6.23
Dixon	8.25	20	5.96	4.17	2.38	7.32	5.12	2.93
Average	8.00	..	8.19	5.73	3.28	11.45	8.01	4.58
V. *Dark soils with impervious, calcareous subsoils*								
Joliet	7.40	18	8.80	6.16	3.52	6.91	4.84	2.77
VI. *Dark soils with impervious, noncalcareous subsoils*								
Carthage	7.75	19	9.87	6.91	3.95	13.31	9.32	5.32
Clayton	7.75	19	11.30	7.91	4.52	13.58	9.51	5.43
Lebanon	8.75	21	9.74	6.82	3.90	14.68	10.28	5.88
Carlinville	9.25	22	15.40	10.78	6.16	13.61	9.53	5.44
Average	8.37	..	11.58	8.11	4.63	13.80	9.66	5.51
VII. *Sandy loams and sands*								
Oquawka	7.90	18	20.02	14.01	8.01	20.67	14.47	8.27
VIII. *Yellow soils with noncalcareous subsoils*								
Unionville	8.75	21	15.90	11.13	6.36	16.56	11.59	6.62
Enfield	7.75	19	22.87	16.01	9.15	21.30	14.91	8.52
Average	8.25	..	19.39	13.57	7.76	18.93	13.25	7.57
IX. *Gray soils with impervious, noncalcareous subsoils*								
Oblong	8.25	20	18.06	12.64	7.22	15.54	10.88	6.21
Toledo	7.25	19	21.98	15.39	8.79	20.57	14.40	8.23
Odin	8.90	30	.....	.....	....	16.79	11.75	6.71
Raleigh	9.25	22	21.77	15.24	8.71	18.89	13.22	7.56
Sparta	6.75	16	20.81	14.57	8.32	22.26	15.58	8.90
Newton	5.50	19	28.85	20.19	11.54	21.35	14.95	8.53
Ewing	9.25	22	26.62	18.63	10.65	23.57	16.50	9.43
Average	7.88	..	23.01	16.11	9.20	19.85	13.90	7.94
X. *Hilly land*								
Elizabethtown	5.25	14	22.24	15.57	8.90	21.37	14.96	8.55

[1]See page 346.

the fields. At the higher prices there is a margin on practically all fields.

The ton-values of the limestone used on these fields at the medium prices for the crop increases are shown graphically in Fig. 26. These values vary more consistently with the natural level of soil productivity than do the acre-values shown in Fig. 25. The spread between the various soil groups in the ton-values of the limestone applied is

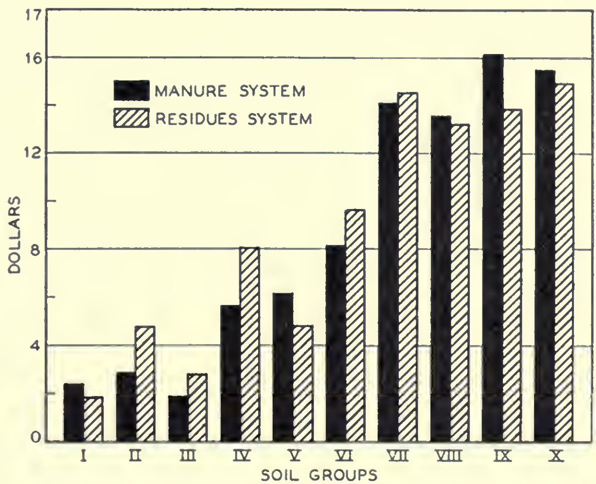

FIG. 26.—TON-VALUES OF LIMESTONE AS MEASURED BY CROP INCREASES

The value of limestone in these experiments tended to vary more consistently with the natural productivity level of the soil than did the acre-values (Fig. 25). The less productive soils have given large returns for each ton of limestone used. (*Based on medium crop prices.*)

also somewhat greater than the spread between the acre-values. The relative differences between the ton-values in the manure system and those in the residues system are similar to the differences shown for the acre-values in the two systems. The striking fact about these results is that each ton of limestone has, as an average, produced crop increases worth more than the cost of the limestone; and that on the less productive light-colored soils the net returns per ton of limestone have been four to five times as great as the investment made.

Problems of Economic Worth

The economic advantages accruing from the use of limestone, or any other fertilizer material for that matter, may be considered from three points of view; namely,

1. The crop point of view; that is, the effect of lime in increasing crop yields.

2. The fertilizer point of view; that is, the margin remaining after the costs of using the limestone have been deducted from the value of the increased yields.

3. The farm point of view; that is, whether, even with increases from the use of limestone, a margin of profit for the farm as a whole remains after all farming expenses have been cared for.

The effectiveness of limestone in increasing crop yields has been amply demonstrated on many Illinois soils. The money returns from increased yields resulting from the use of limestone have, on many soils, been large enough to cover all the costs involved in making the limestone applications and leave margins of varying size.

The fact that a fertilizer may produce large increases in yields or striking money returns per ton of limestone or per acre of crops does not necessarily mean, however, that it can make farming profitable on some soils. The yields without limestone may be so low that any possible increases that might result from the use of limestone would not bring the yields up to a point that would enable a farmer to pay all the expenses of his farm and realize a satisfactory margin of profit. On the Sparta and Odin fields, for example, increases from limestone were excellent, yet the total yields were so small that at ordinary price-levels the total income from such land would not cover even the bare expenses of farming. On the Mt. Morris field, on the other hand, where yields without limestone are high enough to make farming profitable under normal price conditions, increases that were small compared with the Sparta and Odin increases would still be large enough to contribute measurably to further profits.

Thus sizable increases from fertilizers may lead one to false conclusions about their practical value unless note is taken of the basic yields of the soil without fertilizer treatment.

RELATION OF LIMESTONE TO VARIOUS SOIL PRODUCTIVITY FACTORS

The implications involved in such proverbial phrases as "a limestone country is a rich country," led early investigators to believe that limestone could be applied to any soil in any amount without adverse influences except in the matter of unnecessary expense. Such ideas prevailed at the time many of the Illinois soil experiment fields were established. Consequently the plans developed for the use of lime-

stone on these fields provided for its rather liberal use, as described on page 305, in order to make sure that enough would be applied to replace the losses that occur as a natural consequence of cropping and leaching.

With the passing years questions began to arise about whether so much limestone was necessary. If limestone was not lost so rapidly from the soil as had been supposed, then smaller applications or a less frequent use of it would be even more profitable than the larger amounts called for in the early experiments. The advisability of applying limestone at uniform and regular rates on all kinds of soils also began to be questioned. Limestone was not producing profitable increases on some of the experiment fields, probably because it was not needed. Then there arose the question whether excessive quantities of limestone might not have a retarding influence on various soil processes related to crop production. These questions can be considered in the light of existing experiment-field results. Still others can be answered only by further investigation in the field and in the laboratory. A brief discussion of some of these problems is of interest at this point.

Soil Acidity

One of the important functions of limestone is to correct certain conditions that hinder the growth of some legume crops. The most important of these conditions is known as soil acidity.

It is well known that soil acidity varies greatly among soil types and to some extent within the same soil type (see Table 2). Because of this fact it is likely to vary more or less among fields on the same farm and even in different parts of the same field. Thus such legumes as sweet clover, alfalfa, red clover, etc., may grow well on some soil types, or on some fields, or in some parts of a particular field, and grow indifferently or not at all in other places, according to the acidity of the soil.

Since in residues systems of farming the proper utilization of the legume crop has marked effect upon the general crop-producing power of the soil, the farmer's chief interest should be to so maintain the fertility of his soil that legumes will grow abundantly. And since the ability of soils to grow the various legumes successfully is more or less directly related to the degree, or intensity, of soil acidity, the best plan is to use limestone in direct proportion to the intensity of the acidity of the soil. In other words, limestone should be applied only when it is needed to encourage the growth of leguminous crops. Such a practice would often do away with regular applications.

On many of the experiment fields the initial application of limestone is proving effective for longer periods than was anticipated when the fields were established. The results from the West Salem field, described on page 343, for example, are especially significant.

Phosphorus Availability

The opinion is now widely held that a too liberal use of limestone may interfere with the availability of phosphates and especially of applied rock phosphate.

Theoretical reasoning provides justification for the above opinion. There are several forms of calcium phosphates which vary considerably in solubility and hence in availability. Rock phosphate has most of its phosphorus in the form of *tricalcium* phosphate, which is relatively insoluble in water. When acted upon by acids it loses some of its calcium, which is converted into the calcium salts of those acids. When one-third of the calcium is removed, the phosphate becomes *dicalcium* phosphate, and when two-thirds are removed it becomes *monocalcium* phosphate. The more calcium the phosphate loses, the more soluble it becomes and the more available for plant use. However, unless conditions exist that will dispose of the calcium that is lost from the phosphate, it may reunite with the phosphate and again render the phosphate less available.

The growing of such crops as alfalfa, red clover, sweet clover, and others that have high calcium requirements provides one way in which to utilize this calcium. Good drainage may also be helpful in removing it. Soil acids, by uniting with the calcium, are another means of preventing calcium from reuniting with the phosphate. Some soil acidity is likely, therefore, to be of value in rendering phosphates available, especially the phosphates of rock phosphate. If, on the other hand, limestone, which is also a calcium compound, is applied too liberally it may tend to satisfy the calcium requirements of both the high-calcium crops grown and the acids in the soil and in this way prevent the removal of calcium from the phosphate and reduce the effectiveness of the phosphate.

The above reasoning is supported by experiments in the greenhouse and in the laboratory. It is supported also by field investigations in many states, including experiments started on the Aledo field in Mercer county, Illinois, in 1916.

Four carriers of phosphorus have been applied to plots on the Aledo field with and without limestone. Where used, the limestone was applied at the rate of 6 tons an acre. The values of the crop increases

for the phosphates during the last rotation period (1929-1932) are recorded in Table 12. Without exception the phosphates were less effective when applied with limestone than when used alone. This would seem to indicate that limestone reduces the effectiveness of phosphates and that in practice limestone should not be applied with phosphates or at least should be applied only sparingly.

TABLE 12.—AVERAGE ANNUAL ACRE-VALUES OF CROP INCREASES FROM PHOSPHATES USED WITH AND WITHOUT LIMESTONE
(Aledo field, 1929-1932)

Phosphorus carrier	Without limestone	With limestone	Decrease for limestone
Bone phosphate	$7.31	$2.94	$4.37
Superphosphate	6.28	2.37	3.91
Rock phosphate	6.24	1.46	4.78
Slag phosphate	6.51	1.60	4.91

Whether such a conclusion is entirely sound depends upon other considerations. Since both the limestone and the phosphates carried calcium, it is possible that at least part or even all of the effects of the phosphates were in reality due to the calcium, which has a high value on acid soils. It is of interest, therefore, to compare the total combined increases resulting from the limestone and the phosphates when used separately with the increases from these two fertilizing materials when applied together. If the increases from the associated applications were equal to the total combined increases from the separate applications, then it would be clear that limestone and phosphates were exerting independent action on crop yields. If the increases from the associated applications were smaller than the total combined increases from the two separate treatments, then it would appear that these two materials do have some overlapping effects and that one may be substituted for the other to the extent of such overlapping.

As a matter of fact, the increases from limestone and phosphate applied together were considerably smaller than the total combined increases from the separate applications (Table 13), indicating that *under these soil conditions* these two materials do have, in part, a common function. The extent to which overlapping occurred suggests that phosphorus is a relatively unimportant fertilizer on this field, for when the overlapping values are subtracted from the values obtained with phosphate used alone, the increases are hardly sufficient to cover the cost of the phosphate. If calcium is the material most needed, it would appear that limestone alone would be the more

profitable investment. There is of course the possibility that smaller applications of limestone might have permitted larger responses from the phosphate, but the important question is whether such combinations would be as profitable.

While the above conclusions seem applicable to the Aledo field and probably to other kinds of soils also, this does not mean that *all* soils would give similar results. Some soils may be so deficient in phosphorus as to respond satisfactorily to phosphate fertilizers even when

TABLE 13.—AVERAGE ANNUAL ACRE-VALUES OF CROP INCREASES FROM LIMESTONE AND PHOSPHATES USED SEPARATELY AND USED IN COMBINATION
(Aledo field, 1929-1932)

Series	Carrier of phosphorus	Increases from limestone and phosphate used separately			Increases from associated applications	Overlapping effects[1]
		Limestone alone	Phosphate alone	Combined increases		
		(1)	(2)	(3)	(4)	(5)
500	Bone phosphate.....	$6.22	$7.31	$13.53	$9.16	$4.37
	Superphosphate.....	7.33	6.28	13.61	9.70	3.91
	Rock phosphate.....	8.73	6.24	14.97	9.99	4.78
	Slag phosphate......	8.10	6.51	14.61	9.70	4.91

[1]Calculated as the difference between the combined effects when used separately (Column 3) and the increases from associated applications (Column 4).

applied with limestone. The Bloomington field, located in McLean county on a semimature, dark-colored soil that has a heavy, noncalcareous subsoil, has exhibited such a response. On this field rock phosphate used in addition to limestone has given increases in crop yields worth $10.15 an acre annually as an average during the last five years. Superphosphate and bone phosphate applied with limestone have given values of $7.54 and $11.94 respectively. Somewhat similar results have been obtained on other fields. On very acid soils lime applications have long been recognized as essential for best results from phosphates. In these soils the iron and aluminum compounds tend to convert the phosphorus into rather insoluble forms, while limestone tends to keep it in forms more readily available for crop use.

Thus it would appear that type of soil is an important factor in the interaction between limestone and phosphate; and that while some soil acidity may increase the effectiveness of rock phosphate, too intensive acidity may have the opposite effect. So far as phosphorus availability is concerned, therefore, care should be taken to avoid both overliming and underliming. Until these matters are better understood, limestone applications should be made as indicated by a

systematic soil-testing program such as is outlined in Circular 346 of this Station, "Test Your Soil for Acidity."

The interaction between limestone and phosphate in the soil, just discussed, raises another question. If strongly acid soils tend to change phosphorus to the more insoluble iron and aluminum forms, and thus perhaps cause a deficiency of phosphorus for crop production, would the application of limestone without accompanying phosphate applications tend to reduce the phosphorus deficiency? If so, would such reduction remove the necessity for applying phosphates, or at least delay the need for them?

Some preliminary studies, especially those with deep-rooting legumes, indicate that the availability of phosphorus has been greatly increased in some soils so treated and unaffected in others. The problem presents complications that need thoro study before final conclusions can be drawn. It is quite possible, however, that the effectiveness of limestone in making available the supplies of phosphorus naturally in the soil may be a better explanation for the poor crop response to applied phosphate on some soils than an explanation based on the overliming idea.

Potash Availability

Potassium is another plant-food element whose availability may be interfered with by the use of limestone. This is suggested by the results from certain experiments with potash fertilizers and limestone on silt loam soils, practically all of which contain naturally rather large amounts of potassium. Corn yields on the Ewing field, for example, a silt loam, have shown little variation on unlimed land (R) over a period of twenty-three years (Fig. 27). Yields on limed land (RL and RLP) have declined at the rate of three-quarters of a bushel to nearly a bushel annually. Yields on plots given the same treatments as those just mentioned, except for the addition of potassium (RLPK), have increased by more than half a bushel of corn an acre a year, changing from 37.6 bushels in 1910 to 49.3 bushels in 1932.

Experience with alkali soils further strengthens the suggestion that limestone may be involved in the development of a potash deficiency from the standpoint of crop production. It has long been known that alkali soils, which are characterized by high carbonate content, respond markedly to potassium fertilizers even tho the natural content of the soil may be fairly high. The alkali appears to reduce the solubility and availability of the soil potassium. Since the amount of limestone applied in the Ewing experiments and others was some-

what liberal, the effects may be somewhat similar to those in soils where natural alkali conditions exist.

Experiments in Tennessee and elsewhere, showing that the amount of potassium leached from soils can be reduced by applying various kinds of limestone, add further weight to the suggestion that the application of limestone to the Ewing field may have reduced the availability of the soil potassium.

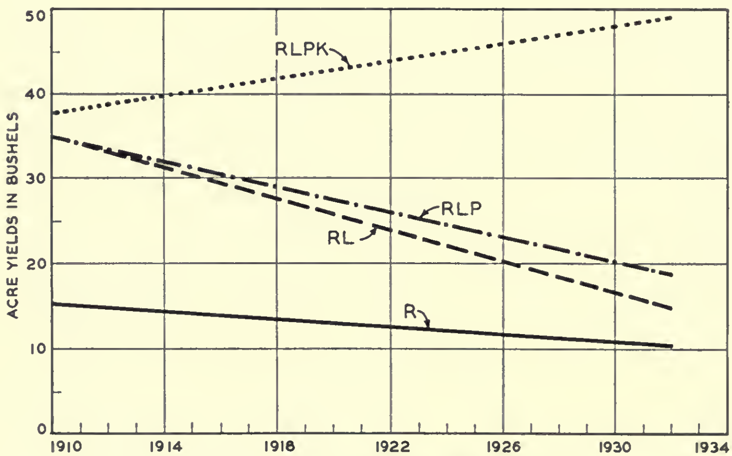

FIG. 27.—EFFECT OF POTASH AND LIMESTONE ON CORN YIELDS ON EWING EXPERIMENT FIELD

On some of the more mature soils the use of limestone appears to lead to a potash deficiency. On the unlimed soil of the Ewing field the corn yields showed a moderate downward trend over a twenty-two year period, but where limestone was applied in addition to crop residues, a much more marked decline occurred. The use of potash fertilizers has resulted in steadily improving yields. (Trends calculated from annual yields by using formula $y = n + mx$.)

Another explanation for the increasing deficiency of available potassium that has accompanied applications of limestone is that limestone, by encouraging larger crops thru the growth of legumes, has caused a greater draft on the natural supplies of available potassium. When these fields were first established, the limestone applied helped materially in growing larger crops. The larger crops naturally took larger amounts of potassium from the soil. As time went on, the amounts of available potassium were depleted faster than the unavailable forms could be converted into forms for crop use, and the plants encountered more and more difficulty in getting the potassium they needed for normal growth. Under such circumstances the applica-

tion of potassium in available form would be expected to have gradually increasing effects on crop yields.

In the Illinois experiments sweet clover, which was always grown on the plots receiving limestone, was usually plowed under the following spring as a green manure for corn. The benefits from applied potash have seemed to increase when the sweet clover was handled in this way, even tho sweet clover itself contains a good percentage of potassium. Some investigators have suggested, in explanation of these results, that a biological factor involving the excessive production of nitrate nitrogen might be responsible for the declining crop yields on limestone-sweet-clover plots to which no potash was applied. Their explanation is that the limestone-sweet-clover combination provides especially favorable conditions for the excessive production of nitrate nitrogen, and that in the absence of sufficient available potassium, large accumulations of nitrate nitrogen may have a detrimental effect on crop growth, especially on a crop like corn. Under such conditions the application of potash fertilizers would have marked beneficial effects.

Whatever the cause may be for the available potassium deficiency under the limestone-sweet-clover system of soil management, it seems safe to conclude that the system has unquestioned merit for large areas of Illinois soils even tho on some soils applications of potash are needed for the best results.

INCREASING USE OF AGRICULTURAL LIMESTONE

The important place that limestone occupies in the management of Illinois soils is clearly demonstrated by the analyses presented in the foregoing pages. The dissemination of facts concerning liming experiments as they have become available, and later the encouragement given soil-testing and mapping by extension agencies, have brought about a widespread use of limestone by Illinois farmers. The first authentic record of the amount of limestone applied to Illinois soils covers the year 1906 and shows a total of 2,000 tons. Continuous and rapid increases took place each year until a peak of 925,000 tons was reached in 1929. This amount, according to statistics published by the National Lime Association, was about one-fourth the total amount of lime materials used for agricultural purposes in the United States that year.

Even tho large tonnages of agricultural limestone have been used

in Illinois, there are still many lime-deficient fields that have never had limestone applied to them. Some of these fields are located on marginal land to which the application of limestone would probably not be economically justified even under more normal times. There are many other fields, however, on which limestone will prove profitable when economic conditions are more normal. There are other soils in the state possessing high levels of productivity that are beginning to show lime deficiencies which will be intensified under continued cultivation unless limestone is applied.

Lime renewals will always need the attention of Illinois farmers, and limestone must remain the key to any successful soil-building program on the lime-deficient soils of the state.[1]

SUMMARY AND CONCLUSIONS

Limestone has long been recognized as of fundamental importance in Illinois agriculture. For the past twenty-five years its use steadily increased until the present depression period. This bulletin analyzes the response of various soils and crops to limestone on forty experiment fields located thruout the state on various kinds of soil, some of the fields having been in operation for thirty years. The principal facts brought out by the study are the following:

1. The degree of response made by Illinois soils to limestone, as measured by crop increases, is closely related to the natural productivity of the soil. Soils of high natural productivity respond least and those of low natural productivity most. The range in response for the different kinds of soils, as measured by yields of all crops grown, varied from nothing to more than 150 percent.

2. The degree of response to limestone bears a close relationship to certain chemical characters of the soil, one of which is the degree of saturation with replaceable calcium and magnesium as compared with the total base-exchange capacity of the soil. Soils with a low percentage saturation respond best to limestone. Soils exhibiting about 80 percent saturation give little or no response. Comparison of the various chemical characters of a soil with its response to limestone indicates the value of proper chemical tests for quickly determining the lime requirements.

3. Different crops respond differently to limestone applications. On the dark-colored soils the response of the corn, oats, wheat, and

[1]See Circular 375 of this Station, "Limestone the Key to Soil Building and Higher Crop Yields," for further discussion of this subject.

hay crops was somewhat similar, tho oats tended to be the least responsive. On the light-colored soils wheat made a much better response than corn, tho all crops, especially hay, made large responses. On sandy soil the differences between the corn and wheat responses were not great; and both crops showed better responses on this soil than on the dark-colored soils. On the sandy soil the application of limestone made the difference between good hay yields and no yields at all.

4. The use of limestone on the light-colored soils has tended to raise the productive levels of such soils to about 50 percent of the levels of the better untreated dark-colored soils. The combined influence of organic manures and limestone has raised the light-colored soils to levels approximately 60 percent as high as the better untreated dark-colored soils.

5. Soils that have shown a high response to limestone applications have tended to show that response quickly. Soils that have shown only a moderate response have tended to be somewhat slow in evidencing that response, tho they usually have shown considerable acceleration in response after the first or second rotation. Some highly productive soils have shown no response until recent years, indicating that there has been a slow development of lime deficiency. Some soils, after exhibiting considerable acceleration in their response for a number of years, have then shown a leveling out of response and then a falling off. Such behavior is probably due to increasing deficiencies in the supplies of other plant nutrients. On many soils increases from limestone have continued for some years after applications have been discontinued, showing the cumulative effect of proper applications of limestone.

6. Increasingly larger crop yields for eight years were obtained from a single 4-ton application of limestone on a lime-deficient light-colored soil. After eight years there was a leveling out of the response and then a decline. After twenty years, however, the single application still showed some effect on crop yields. Repeated applications during this twenty-year period proved no more effective than the single application until after the eighth year, when greater crop increases were shown for them than for the single application.

7. Limestone should be applied in amounts meeting rather closely the actual crop requirements. Smaller amounts may be altogether without effect. Larger amounts will be not only uneconomical but they may tend to reduce the availability of other plant nutrients, such as phosphorus and potassium. These facts indicate the value of definite

tests by which the lime deficiency of given fields or parts of fields may be quickly and accurately judged.

8. The thirty years of experimental evidence summarized here indicates that lime materials are—

a. Indispensable for successful crop production on many soils.

b. Highly desirable for efficient production on other soils.

c. Without much actual or economic effect on other soils.

There is also evidence showing that nonresponsive soils may, with continued cultivation, become sufficiently lime-deficient to respond to limestone applications; and that the chemical, physical, and biological changes produced by the application of lime materials may in time create new soil conditions that have to be recognized in management practices.

For the practical application of the facts discussed in this bulletin, see—

Circular 346, "Test Your Soil for Acidity"
Circular 375, "Limestone the Key to Soil Building and Higher Crop Yields"